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HYDRAULIC CHARACTERISTICS OF THE DEER CREEK LAKE LAND TREATMENT--ETC(U)
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Hydraulic characteristics of the Deer Creek Lake land treatment site during wastewater application

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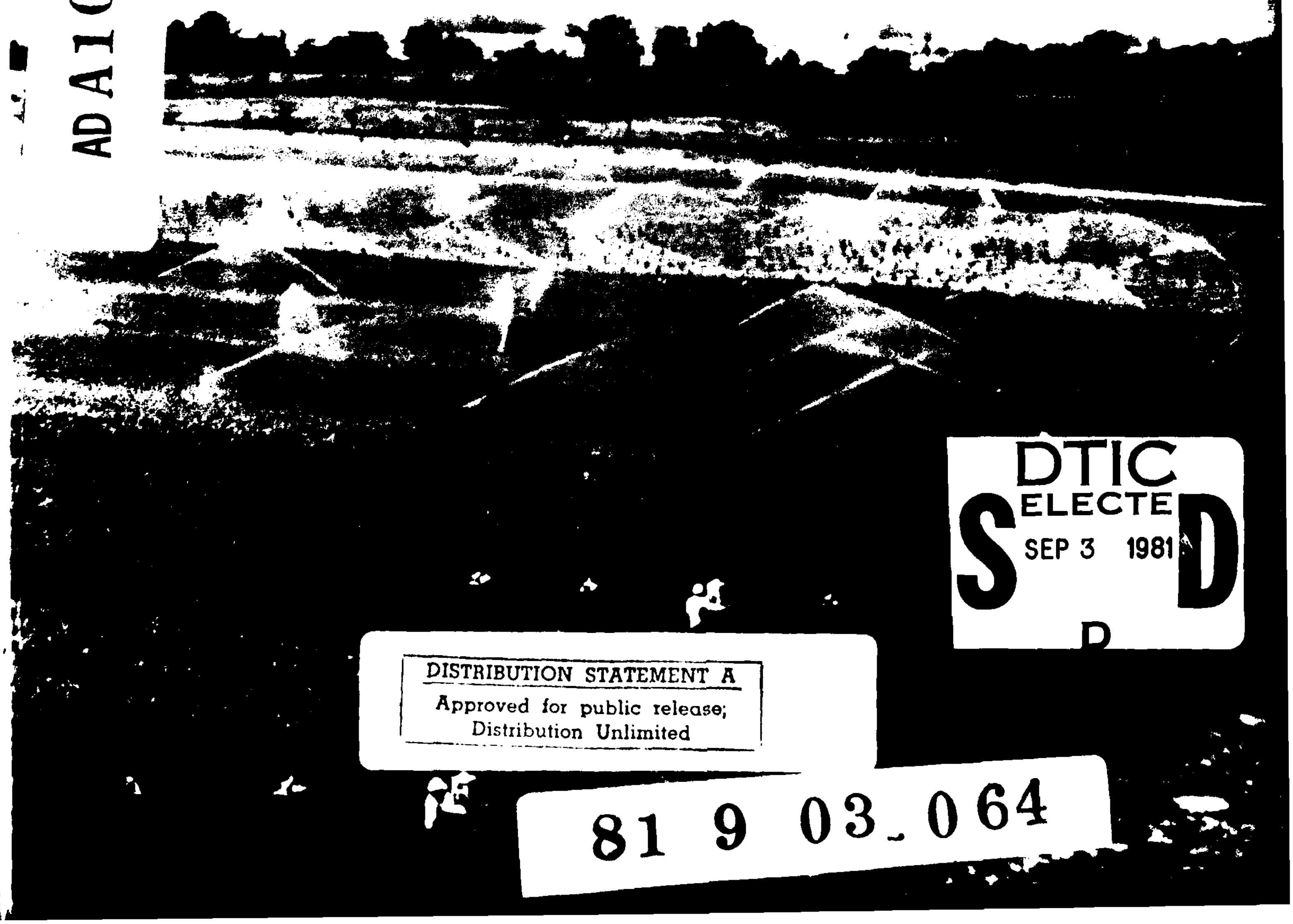

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

Cover: *Spraying wastewater at Deer Creek Lake land treatment site. (Photograph by Huntington District, Corps of Engineers.)*

CRREL Report 81-7

Hydraulic characteristics of the Deer Creek Lake land treatment site during wastewater application

G. Abele, H.L. McKim, D.M. Caswell and B.E. Brockett

April 1981

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During the summer of 1979, wastewater was applied 10 times to the Deer Creek Lake, Ohio, land treatment site. Wastewater distribution on the ground during spray application is not uniform; some locations receive less than 70% and others more than 130% of the mean amount applied. The saturated infiltration rate ranges from moderately slow (0.6 cm/hr after 1 hr) to slow (0.3 cm/hr after 12 hours) and can be expressed by $I \approx 0.6\, t^{-1/4}$ cm/hr. The underdrain flow rate increases approximately as the cube of time until 1 hour after the end of application and then decreases as the reciprocal of time squared. The rate and amount of drainage increases with an increase in the initial soil water content and can be predicted from soil tension measurements. It was possible to calculate the mass water budget at the end of a typical application to within 88% of the actual water applied.

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PREFACE

This study was conducted by Gunars Abele, Research Civil Engineer, and David M. Caswell, Civil Engineering Technician, of the Applied Research Branch, Experimental Engineering Division, and by Dr. Harlan L. McKim, Soils Scientist, and Bruce E. Brockett, Physical Science Technician, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Jonathan Ingersoll, Civil Engineering Technician, Geotechnical Research Branch, Experimental Engineering Division, participated in the infiltration field test and in the soil data collection.

This work was performed during 1979 at the Deer Creek Lake land treatment site under U.S. Army Engineer District, Huntington, West Virginia, Intra-Army Order No. E 8679ED-03. This report was technically reviewed by John Bouzoun, C. James Martel and Carolyn Merry of CRREL and by Dr. Satish C. Gupta, U.S. Department of Agriculture, University of Minnesota.

Appreciation is expressed to the staff of the Deer Creek Lake Corps of Engineers Office at Mt. Sterling, Ohio, for their support and assistance during the 1979 test season.

CONTENTS

ILLUSTRATIONS

TABLES

NOMENCLATURE

A_T	total area of spray field (three 3-acre plots = 9 acres = 3.64 ha)
d	distance from spray nozzle (m)
G_s	specific gravity of soil
h	soil tension (cm of water)
h_0	initial soil tension (cm of water)
h_w	height of water (cm)
I	infiltration rate (cm hr^{-1})
n	slope of line on log-log plot
Q	drainage rate (L hr^{-1})
Q_{max}	peak drainage rate (L hr^{-1})
S	saturation (%); $S = V_w \times V_v^{-1} \times 100$
t	time (hr)
V	cumulative drainage (L)
V_a	volume of air (%); $V_a = V_v - V_w$
V_s	volume of solids (%); $V_s = \gamma \times G_s^{-1} \times 100$
V_T	total volume of spray field ($A_T \times z_T \cong$ 29,144,500 L $\cong$ 7,700,000 gal.)
V_v	volume of voids (%)
V_w	volumetric water content (%); $V_w = w(\gamma \times \gamma_w^{-1})$
V_W(applied)	volume of water applied (L)
V_W(soil)	amount of applied water remaining in soil (L); $\Delta V_w \times V_T$
w	gravimetric water content (%); $W_w \times W_s^{-1} \times 100$
W_s	dry weight of solids (g)
W_w	weight of water (g)
Y	cumulative water intake (cm)
z	depth (cm)
z_T	total effective depth of spray field $\cong$ depth of underdrains $\cong$ 80 cm
Δh_w	change or difference in height of water (cm)
Δt	time increment (hr)
ΔV_w	change in volumetric water content (%)
ΔY	incremental intake (cm)
γ	dry density of soil (g cm^{-3})
γ_w	density of water (assume 1 cm^3 = 1 g)

HYDRAULIC CHARACTERISTICS OF THE DEER CREEK LAKE LAND TREATMENT SITE DURING WASTEWATER APPLICATION

G. Abele, H.L. McKim, D.M. Caswell and B.E. Brockett

INTRODUCTION

The Deer Creek Lake land treatment system, located approximately 48 km (30 mi) southwest of Columbus, Ohio, treats wastewater from a camping site. The facility, designed to handle a flow of 174,000 L per day (46,000 gal./day) is composed of a stabilization lagoon, a holding lagoon, a pumping system that transports wastewater to the treatment site, and a rotating nozzle spray distribution system that applies wastewater on four 1.21-ha (3-acre) test plots, using nozzle spacing of 12 m (40 ft) longitudinally and 18 m (60 ft) laterally. An underdrain system with a lateral spacing of 9 m (30 ft) collects the percolate water at a depth of approximately 75 to 80 cm (approx. 30 in.) and terminates at a point where the discharge can be diverted either back to the stabilization lagoon or discharged into Deer Creek Lake (Fig. 1). The four test plots were planted with reed canarygrass, corn, alfalfa, and tree seedlings.

The treatment system was designed by the Huntington District, U.S. Army Corps of Engineers. The operation and performance of the system have been described by Lambert and McKim (1977).

The primary objectives of this study were to determine the infiltration and drainage rates at this land treatment site and the total water mass balance during wastewater application. These data are needed to predict the land treatment system's performance capabilities if the amount of water to be treated should need to be increased significantly.

A study was also conducted on the actual distribution of the wastewater over the area during the spray application. During the 1978 and 1979 test seasons, it was observed that the soil water content data, obtained at random locations over the sprayed area during and after the applications, frequently produced unrealistic and conflicting results (water content data did not always reflect an appropriate increase in the water content values after water application). It was suspected that an uneven distribution of the sprayed water might account to some degree for the lack of a consistent correlation between the calculated amount of water applied and the expected corresponding increase in water content.

The results of the 1978 test season at Deer Creek Lake have been described and analyzed in a previous report (Abele et al. 1979).

DESCRIPTION OF STUDY

Wastewater application schedule

During the summer of 1979, wastewater was applied to the test area a total of 10 times. The amounts varied between 2.35 and 2.82 cm (0.92 and 1.11 in.) of water, or between 855,640 and 1,026,340 L (226,060 and 271,160 gal.) over a 3.64-ha (9-acre) area (Table 1). Wastewater was

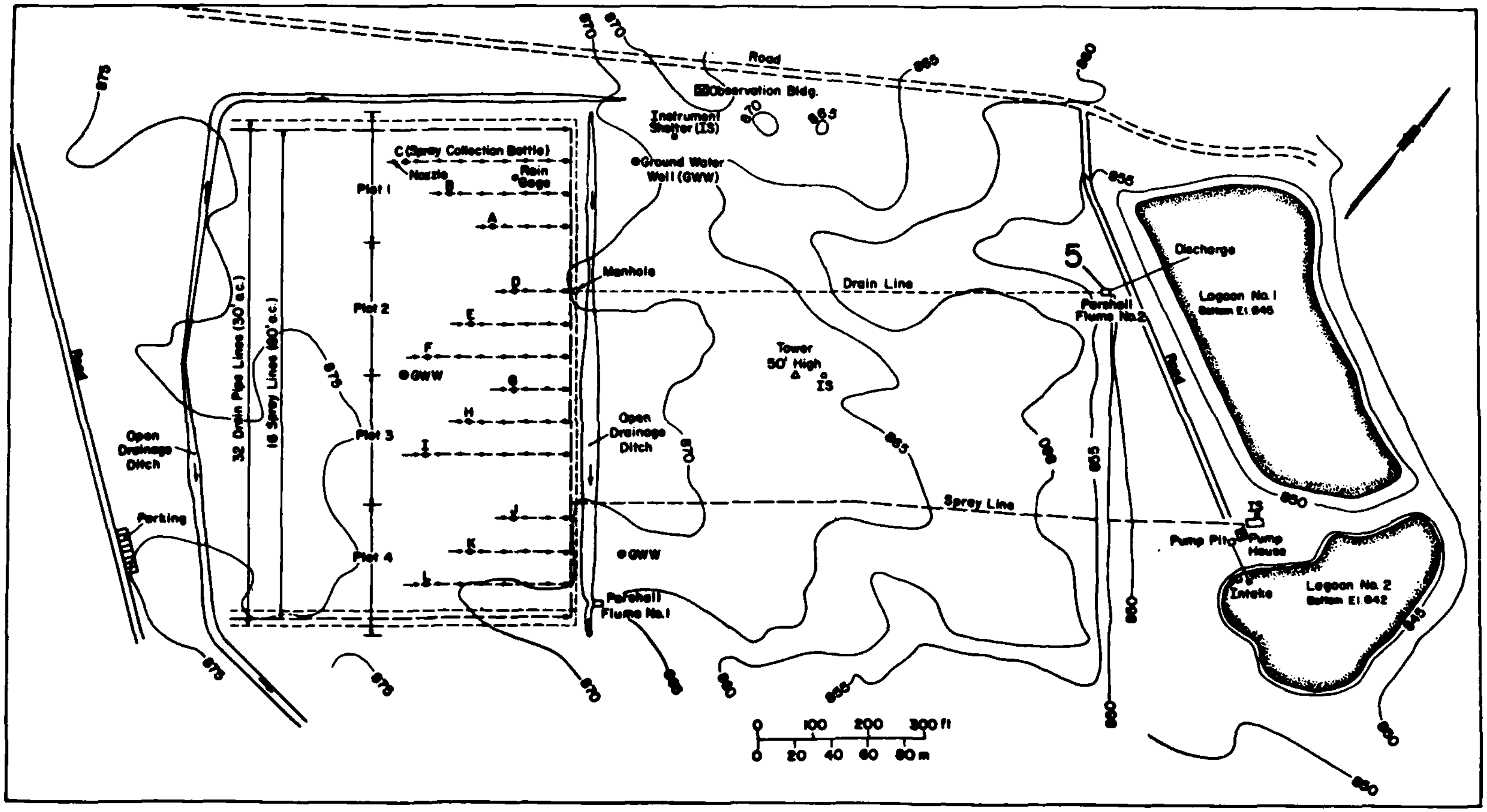


Figure 1. Deer Creek Lake land treatment site. (Point 5 indicates site where underdrain flow measurements were obtained.)

Table 1. Application schedule.

No.	Date	Amount applied (L)	(gal.)	(cm)	(in.)	Application procedure
			1979			
1	10 June	997,590	258,280	2.68	1.06	Continuous (5 hr)
2	24 June	1,026,340	271,160	2.82	1.11	Continuous (5 hr)
3	1 July	967,900	255,720	2.66	1.05	Continuous (5 hr)
4	8 July	996,060	263,160	2.73	1.08	Continuous (5 hr)
5	15 July	960,820	253,850	2.64	1.04	Continuous (5 hr)
6	22 July	959,190	253,420	2.63	1.04	Continuous (5 hr)
7	7 Aug	967,140	255,520	2.65	1.05	Continuous (5 hr)
8	14 Aug	1,004,010	265,260	2.76	1.09	Continuous (5 hr)
9	20 Aug	1,004,010	265,260	2.76	1.09	Continuous (5 hr)
10	29 Aug	855,640	226,060	2.35	0.92	15 min on, 15 min off
			1978			
7*	2 Aug	990,900	261,800	2.72	1.07	1 hr on, 20 min off
9*	15 Aug	946,300	250,000	2.60	1.02	30 min on, 30 min off

Total area sprayed = 3.64 ha (9 acres).
Equivalent cumulative height of water applied:
1 cm ≈ 364,300 L (96,250 gal.)
1 in. ≈ 244,500 gal. (925,400 L).
*Data from previous season used for comparison in drainage analysis.

applied only on the reed canarygrass, corn and alfalfa plots; the plot containing the tree seedlings was not used.

The rate of application, dictated by the spray system's capacity, was approximately 0.5 cm hr^{-1} (0.2 in. hr^{-1}). The first nine applications were done without interruption, requiring approximately 5 hr. The last application was done on an intermittent (15 min on, 15 min off) schedule, lasting approximately 10 hr.

Observation schedule

Climatological data, consisting of air and water temperature (maximum and minimum), precipitation, mean wind speed, and pan evaporation, were obtained daily from the climatological station near the lagoons (Fig. 1) and are listed in Table A1 in Appendix A.

Soil tension data were obtained from the tensiometers installed at four depths in each of the grass, corn, and alfalfa plots at the beginning of the test season. Tension readings were usually obtained according to the following schedule:

1. Prior to application (t = 0 hr)
2. During application (t = 2 to 3 hr)
3. Shortly after application (t = 5 to 8 hr)
4. One day after application (during the a.m. and usually again during the p.m.)
5. Two days after application (usually twice)
6. Daily thereafter until the next application

The data are listed in Table A2.

Soil moisture content data were obtained on a schedule similar to that used for the soil tension observations. At least one soil core to a 90-cm (35-in.) depth was obtained at an arbitrary location in the 3.64-ha (9-acre) sprayed area prior to, during, and at various times after each application for moisture content determinations at approximately 10-cm (4-in.) depth increments. The data are listed in Table A3.

Underdrain flow measurements were made at point 5 (refer to Fig. 1) to monitor the rate of water movement through the soil after application. Several measurements were obtained during and after each application and continued for several days with one to three measurements each day. The data are listed in Table A4.

The specific gravity of the soil and the soil density profiles of the three plots had been determined previously (Abele et al. 1979). Additional density data were obtained in the grass plot in connection with the infiltration test.

Wastewater and percolate samples were collected each week from the various monitoring points for chemical and biological analyses. This work will be discussed in a separate report prepared by Ohio State University.

Infiltration test

An in-situ infiltration test was conducted on the reed canarygrass plot (Fig. 2) on 16 August 1979 using a 6.1-m- (20-ft-) diam. area with a seal

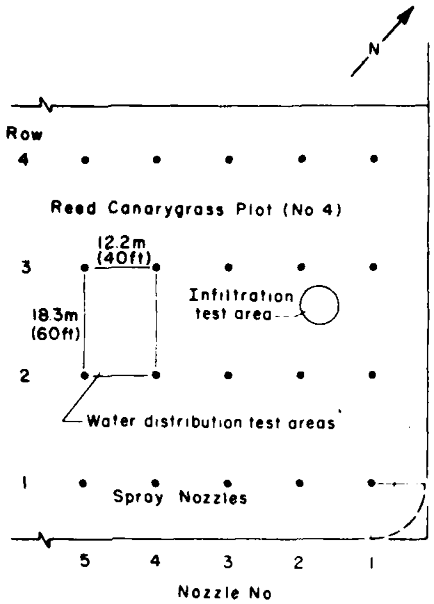


Figure 2. Locations of test areas.

around the periphery of the test surface to prevent surface runoff (Fig. 3). Aluminum flashing, 35 cm wide, was installed in a 15-cm-deep, precut groove, leaving a 20-cm-high wall around the test area. Tensiometers were installed 30 cm apart in three radial rows at five depths (that is, a total of three tensiometers at each depth). Soil tension data were obtained from periodic tensiometer readings and soil water content data from cores obtained prior to and at various times after water application. Infiltration data were obtained from periodic observations of head drop (cumulative intake) read from graduated scales on the inside of the aluminum berm. Water was applied at a rate of approximately 0.5 cm min^{-1} (0.2 in. min^{-1}).

In the test, 2.5 cm (1 in.) of water was first applied to observe the infiltration rate for an unsaturated soil condition. The second application, a total of 8.5 cm (3.4 in.) of water, was made 3.3 hr later after the soil had reached a nearly saturated condition. A completely saturated condition was reached shortly after the second application. The cumulative intake during the steady state (saturated) condition was monitored for 16.3 hr.

Water distribution tests

To observe the actual distribution of the wastewater when sprayed on the test plots by the rotating spray nozzles arranged in a 12.2- × 18.3-m (40- × 60-ft) rectangular grid (Fig. 2), 3.8-L (1-gal.) plastic buckets were placed in an arrangement shown in Figure 4 within one of the rectangular areas enclosed by four spray nozzles during application 6 (22 July). After the wastewater application, the volume of water in each of the 21 buckets was measured using a 1000-mL graduated cylinder. The volume measurements were converted to height of water values based on the open area (324.3 cm^2) of the top of the bucket. (The sides of the buckets were slightly flared, therefore, a direct measurement of the height of water in the bucket would not be the true height.)

Since the spray circles overlap, the results from this test represent the combined effect from either two, three, or four nozzles, depending on the particular location within the rectangle. To determine the spray pattern of each individual nozzle or the variations in the amount of water deposited with distance from each nozzle, the outside corner 90° sector of the grass field was used (refer to Fig. 2). In this area, which was subjected to spray from only one nozzle, 21 buckets were arranged as shown in Figure 5. Measurements of the amount of water in each bucket were done after applications 7, 8, and 9.

a. Tensiometer arrangement.

b. Water application.

Figure 3. Infiltration test.

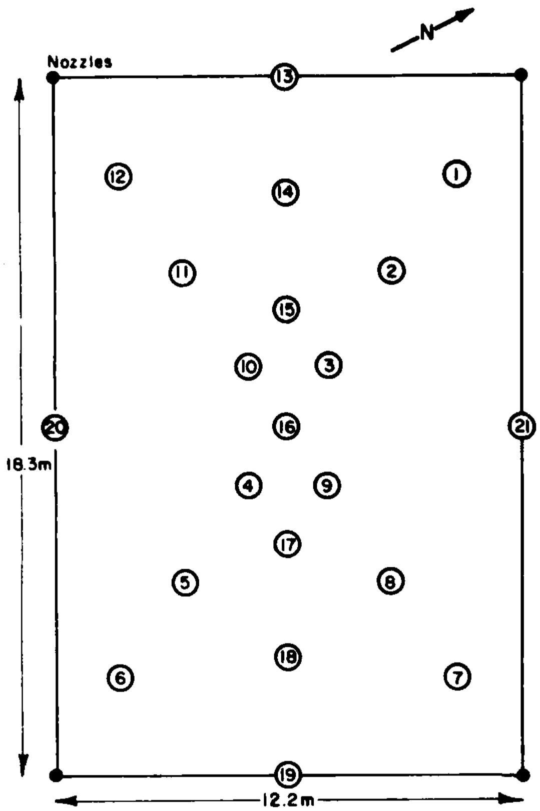


Figure 4. Bucket arrangement during appl. 6.

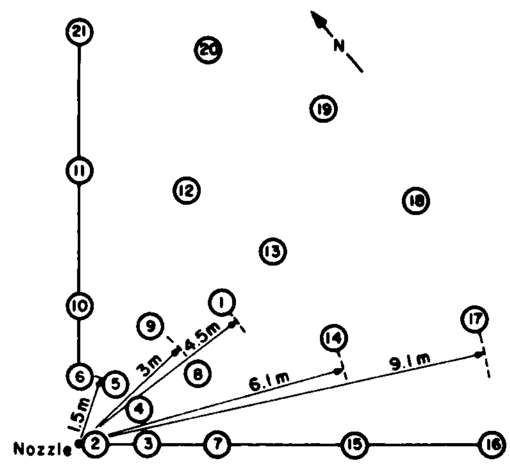


Figure 5. Bucket arrangement during appl. 7, 8 and 9.

DISCUSSION OF RESULTS

Infiltration rate

If the cumulative intake Y vs time t data can be represented by a straight line on an arithmetic plot, the infiltration rate, being a constant, can be obtained directly from

$$I = Yt^{-1}. \tag{1}$$

Ordinarily, however, the cumulative intake vs time relationship is curvilinear, the intake decreasing gradually with time. This relationship can usually be represented by a straight line on a log-log plot and, therefore, can be expressed by

$$Y = Ct^{n} \tag{2}$$

where C is the intercept at $t = 1$ and n is the slope.

Since $I = dY/dt$, I can then be derived:

$$I = Cnt^{n-1}. \tag{3}$$

This is the commonly used expression for the infiltration rate as a function of time. Plotting the individual infiltration rate values (calculated from the incremental intake and time measurements) vs time usually results in considerable data scatter.

The density and water content of the soil prior to the infiltration test are shown in Table 2 and plotted in Figure 6. The volumetric composition of the soil is shown in Figure 7. The initial saturation of the soil in the test area was 82% (mean). The soil tension data are listed in Table 3 and plotted in Figure 8. The tension observations were used to monitor the relative degree of saturation after the water application, since it was not possible to obtain soil cores because of water on the surface of the test area.

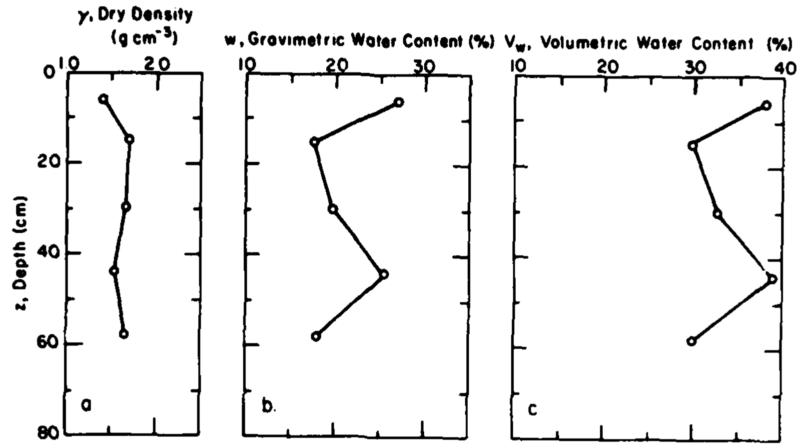


Figure 6. Soil density and water content vs depth at infiltration test site (before application).

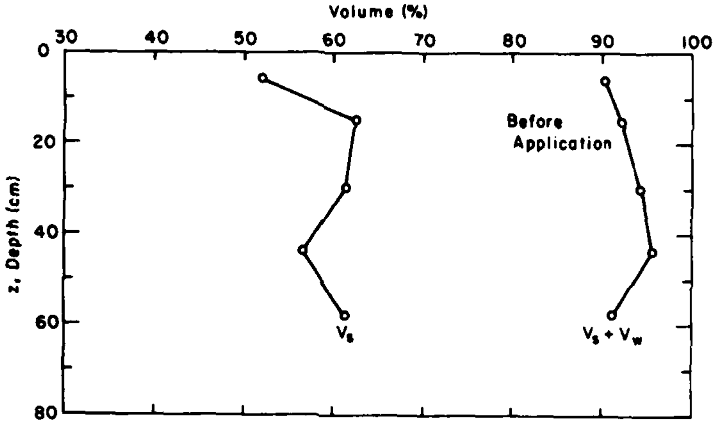


Figure 7. Volumetric composition of soil at infiltration test site.

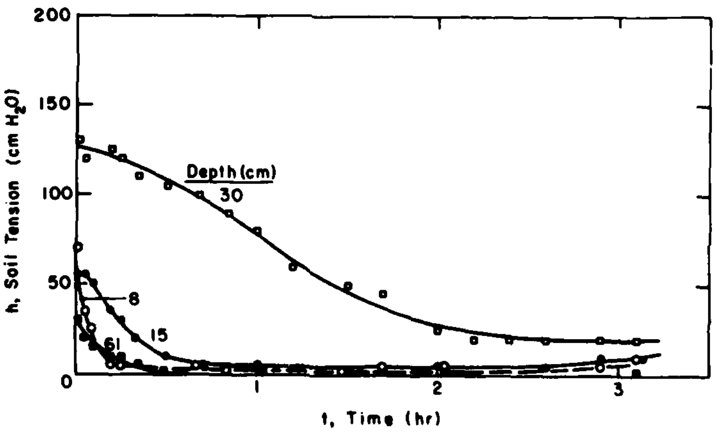


Figure 8. Soil tension vs time at various depths for first application.

Table 2. Volumetric composition of soil prior to infiltration test.

Depth	Density	Gravimetric (%)	Volumetric (%)			
z	γ	w	V_w	V_s	V_v	$V_w + V_s$
(cm)	(g cm⁻³)			(G_s = 2.71)		
6	1.41	27.0	38.1	52.0	48.0	90.1
15	1.69	17.6	29.7	62.4	37.6	92.1
30	1.66	19.8	32.9	61.3	38.7	94.2
44	1.53	25.5	39.0	56.5	43.5	95.5
58	1.66	17.9	29.7	61.3	38.7	91.0

Table 3. Soil tension during infiltration test.

Tension data represent means of three observations

	Depth (cm)				
	8	15	30	61	86
Time	Soil tension (cm of water)				
0	70	55	130	30	20
		1st application = 2.5 cm			
3 min	35	55	120	20	10
5 min	25	50	120	15	0
11 min	5	35	125	10	0
15 min	5	30	120	10	0
20 min	5	20	110	5	0
30 min	5	10	105	0	0
40 min	5	5	100	0	0
50 min	0	0	90	0	0
1.0 hr	0	5	80	0	0
1.2 hr	0	5	60	0	0
1.5 hr	0	5	50	0	0
1.7 hr	5	5	45	0	0
2.0 hr	5	5	25	0	0
2.2 hr	5	5	20	0	0
2.4 hr	5	5	20	0	0
2.6 hr	5	5	20	0	0
2.9 hr	5	10	20	0	0
3.1 hr	10	10	20	0	0
		2nd application = 8.5 cm			
1hr	0	0	0	0	0

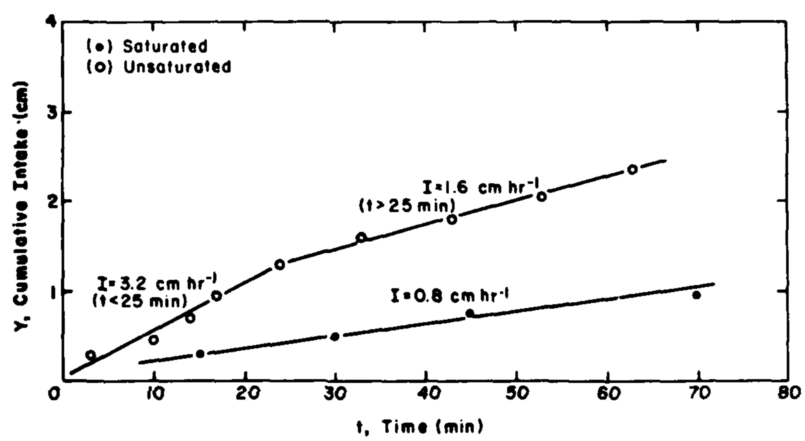


Figure 9. Cumulative intake vs time (first hour).

Table 4. Cumulative intake during infiltration test.

Time *(hr)*	*Intake* *Y* *(cm)*	*ΔY* *(cm)*	*Δt* *(hr)*	*Rate* *I* *(cm hr^{-1})*	*t* (hr)
			Unsaturated condition		
0	0				
		0.3	0.05	6.0	0.025
0.05	0.3				
		0.15	0.12	1.25	0.11
0.17	0.45				
		0.25	0.06	4.17	0.20
0.23	0.7				
		0.25	0.05	5.0	0.255
0.28	0.95				
		0.35	0.12	2.92	0.34
0.40	1.3				
		0.3	0.15	2.0	0.475
0.55	1.6				
		0.2	0.17	1.18	0.635
0.72	1.8				
		0.25	0.16	1.56	0.80
0.88	2.05				
		0.3	0.17	1.76	0.965
1.05	2.35				
			Saturated condition		
0	0				
		0.3	0.25	1.2	0.13
0.25	0.3				
		0.2	0.25	0.8	0.38
0.5	0.5				
		0.25	0.25	1.0	0.63
0.75	0.75				
		0.2	0.45	0.44	0.98
1.2	0.95				
		0.45	0.7	0.64	1.55
1.9	1.4				
		1.0	2.1	0.48	2.95
4.0	2.4				
		4.1	12.3	0.33	10.15
16.3	6.5				

The cumulative intake vs time data for both the unsaturated and saturated soil conditions during the first hour after application are plotted on arithmetic scales in Figure 9 (refer to Table 4).

For the unsaturated condition, there is an apparent break in the Y vs t line at some time between 20 and 30 minutes, indicating a variable infiltration rate for the 1-hr period, the time required for the 2.5 cm of water to enter the soil.

For the saturated condition, the cumulative intake was relatively constant for the first hour (Fig. 9), but thereafter the intake rate decreased gradually with time (Fig. 10).

When plotted on a log-log plot (Fig. 11), the Y vs t data from the unsaturated condition follow an irregular curvilinear pattern, as was already implied in Figure 9. The straight line shown in Figure 11 for the unsaturated condition represents the best-fit line estimated by eye, which results in the following expression:

$$Y = 2.3\,t^{0.76}\,(\text{cm}) \tag{4}$$

or

$$Y = 0.91\,t^{0.76}\,(\text{in.})$$

$(t = \text{hr})$.

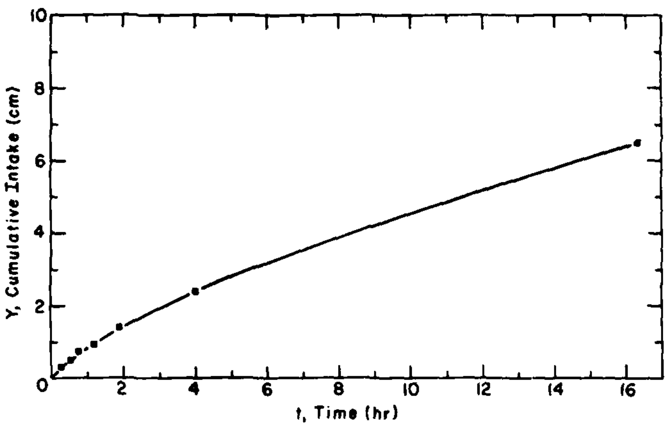


Figure 10. Cumulative intake vs time (saturated condition).

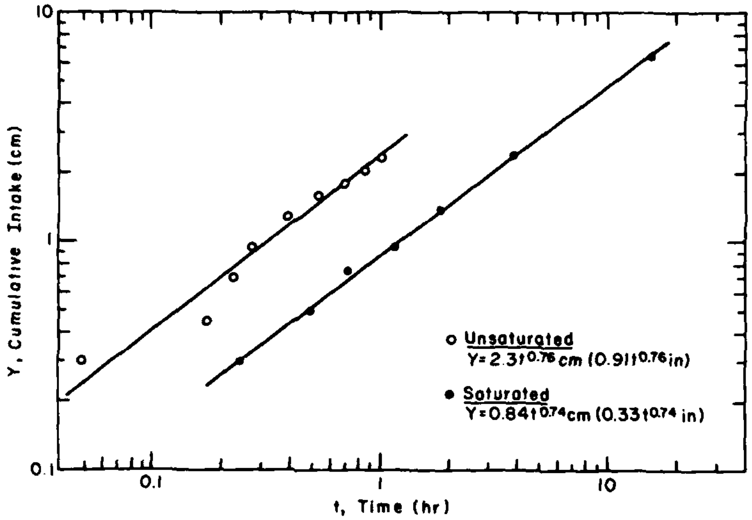


Figure 11. Cumulative intake vs time (log-log).

For the saturated condition, the Y vs t relationship can be quite easily represented by a straight line (Fig. 11) and the expression

$$Y = 0.84\, t^{0.74}\,(\mathrm{cm}) \qquad (5)$$

or

$$Y = 0.33\, t^{0.74}\,(in.).$$

The slopes of the Y vs t lines are practically the same for both the unsaturated and saturated soil conditions.

The computed infiltration rates (from eq 3) are as follows:

Unsaturated (S = 82%):

$$I = 1.75\, t^{-0.24}\,(\mathrm{cm\ hr^{-1}}) \qquad (6)$$

or

$$I = 0.69\, t^{-0.24}\,(\mathrm{in.\ hr^{-1}})$$

Saturated:

$$I = 0.62\, t^{-0.26}\,(\mathrm{cm\ hr^{-1}}) \qquad (7)$$

or

$$I = 0.24\, t^{-0.26}\,(\mathrm{in.\ hr^{-1}}).$$

The computed infiltration rate as a function of time is shown in Figure 12.

As mentioned earlier, the infiltration rate can also be calculated from the individual field measurements (Table 4), or obtained from the

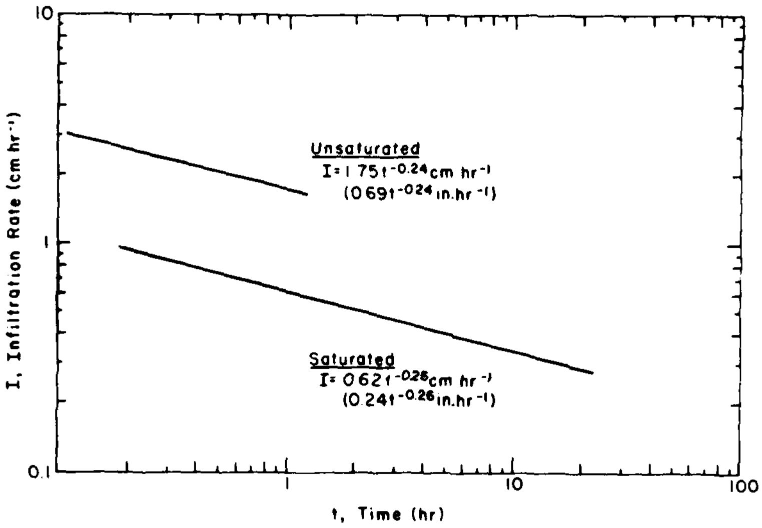


Figure 12. Computed infiltration rate vs time.

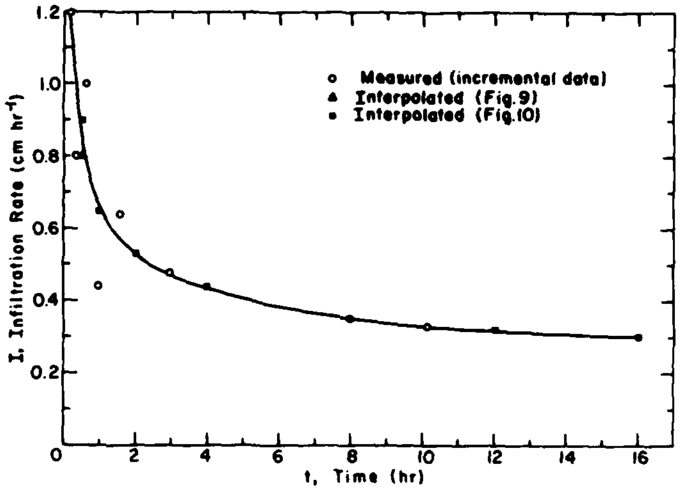


Figure 13. Infiltration rate vs time.

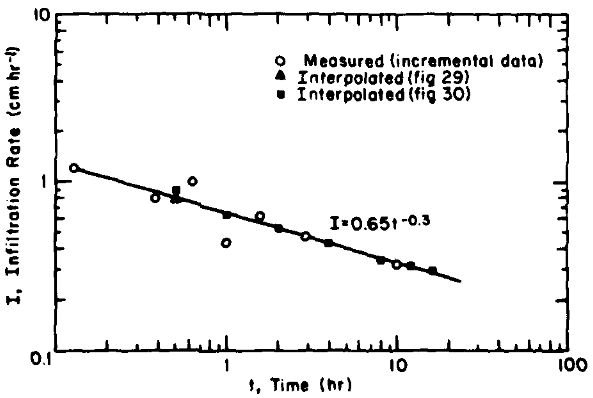


Figure 14. Infiltration rate (saturated condition) vs time (log-log).

slope of the Y vs t lines in Figure 9 and from the slope of the tangent to the curve at any t value in Figure 10. The results of this method for the saturated condition are plotted in Figure 13 (arithmetic plot) and Figure 14 (log-log plot). The agreement between the calculated infiltration rate (Fig. 12) and that determined from the incremental measurements and interpolated values (Fig. 14) is very close:

When calculated from the log Y vs log t relationship (Fig. 11)

$$I = 0.62\ t^{-0.26}\ (\mathrm{cm\ hr^{-1}})$$

When determined from the best fit line for incremental values (Fig. 14)

$$I = 0.65\ t^{-0.3}\ (\mathrm{cm\ hr^{-1}}). \tag{8}$$

For the unsaturated case, the incremental infiltration rate vs time plot resulted in an extreme data point scatter.

The straight line Y vs t arithmetic relationship for the unsaturated condition (Fig. 9) may be a more realistic representation of the true infiltration rate than that represented by eq 6 which was calculated from the log Y vs log t relationship in Figure 11:

When measured from the Y vs t relationship (Fig. 9)

$$I = 3.2\ \mathrm{cm\ hr^{-1}}\ (t < 0.5) \tag{9}$$

$$I = 1.6\ \mathrm{cm\ hr^{-1}}\ (t > 0.5\ \mathrm{hr}) \tag{10}$$

When calculated from the log Y vs t relationship (Fig. 11; eq 6)

$$I = 1.75\ t^{-0.24}\ (\mathrm{cm\ hr^{-1}}).$$

It should be noted that the cumulative intake and the infiltration rate for an unsaturated condition will vary depending on the soil water content or the degree of saturation prior to the water application. The Y and I values shown here are applicable only to that particular soil water content condition and the degree of saturation at the time of the test.

According to the U.S. Department of Agriculture Soil Conservation Service Permeability Classification for saturated soils (U.S. EPA 1977) the soil permeability at this site corresponds to a range of moderately slow (0.6 cm hr^{-1} at 1 hr) to slow (0.3 cm hr^{-1} after 12 hr).

Water distribution

The results of the spray distribution from a single nozzle are listed in Table 5 and plotted in Figure 15. The graph shows how the amount of water deposited on the ground decreases with the distance from the nozzle. The mean amount of water applied over the entire test area during the three applications was 2.72 cm (1.07 in.) per application.

The extent of the spray was approximately 12.5 m (41 ft). Therefore, the overlap of the spray in the rectangular area enclosed by four nozzles would be as shown in Figure 16. The curve from Figure 15, representing the mean amount of water deposited by one nozzle during one application, is also shown in Figure 16. The amount of water received at any location within the rectangle can be visualized by rotating the shaded h_w vs d figure around each nozzle. For example, the center of the rectangle, which is 11 m from each nozzle, receives some spray (in this case 0.5 cm) from each nozzle for a total of 2.0 cm, which is less than the mean amount (2.72 cm) applied. It is immediately obvious that some locations receive noticeably less water and other areas more than the average amount applied.

If it is assumed that the curve in Figure 15, representing the mean water distribution observed during three separate water applications, is a reasonable representation of the spray pattern from all other nozzles in the test area, the total amount of water deposited at any location within the sprayed area can be determined by adding the amounts of water contributed by each nozzle.

A coordinate grid system was established as shown in Figure 17. (Because of symmetry, only one quarter of the rectangular area is required for this exercise.) The distance from each point in the grid to each nozzle was measured, and the amount of water contributed by each nozzle to that grid point was determined from the curve in Figure 15. The results are tabulated in Table 6 and plotted in Figure 18. For example, the point 1,1 in Figure 17 received 1.4 cm of water from nozzle A, 0.55 cm from nozzle B, 0.15 cm from nozzle C, and no water from nozzle D, for a total of 2.10 cm. The values in the center of each grid square (denoted by letters in Fig. 17) were determined by averaging the values at the corners of each grid square (Fig. 18).

The mean of the grid square center values was 2.66 cm, which was equivalent to 97.8% of the mean amount (2.72 cm) sprayed on the area. Therefore, the agreement between the results of

Table 5. Water distribution from one nozzle.

Bucket no.	Dist., d (m)	Application no. 7	8	9	Mean
		Height of water, h_w (cm)			
2	0	—	4.09	3.35	3.72
3	1.5	3.79	3.21	2.08	
4	1.5	3.08	2.28	1.88	
5	1.5	2.31	2.11	1.85	
6	1.5	2.41	2.79	2.11	
Mean	1.5	2.90	2.60	1.98	2.49
7	3.0	3.39	3.01	1.88	
8	3.0	2.73	1.43	1.60	
9	3.0	1.99	1.51	1.85	
10	3.0	1.28	2.36	2.39	
Mean	3.0	2.35	2.08	1.93	2.12
1	4.5	2.04	—	—	2.04
11	6.1	1.02	2.42	2.08	
12	6.1	1.45	1.57	1.82	
13	6.1	1.80	1.82	1.82	
14	6.1	2.20	2.10	1.73	
15	6.1	1.71	—	1.83	
Mean	6.1	1.64	1.98	1.86	1.83
16	9.2	—	1.16	1.23	
17	9.2	0.39	1.39	1.19	
18	9.2	0.46	1.28	1.09	
19	9.2	0.91	1.50	1.23	
20	9.2	1.39	1.42	1.13	
21	9.2	1.17	1.28	1.13	
Mean	9.2	0.86	1.34	1.17	1.12

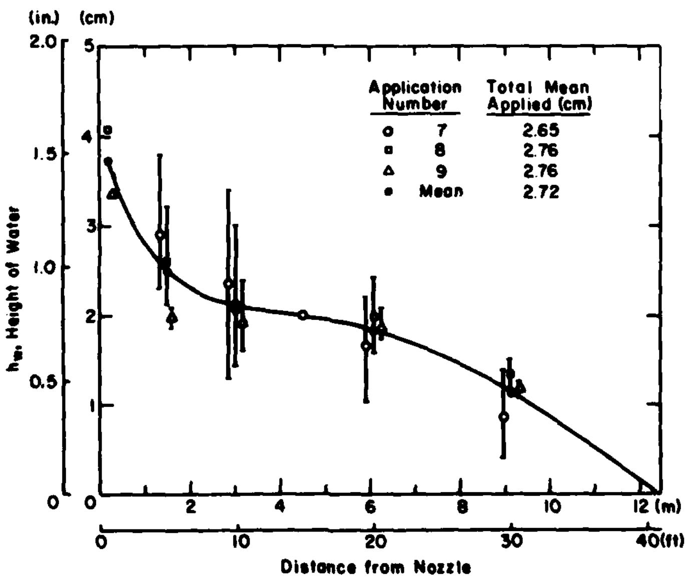


Figure 15. Water applied from one nozzle vs distance.

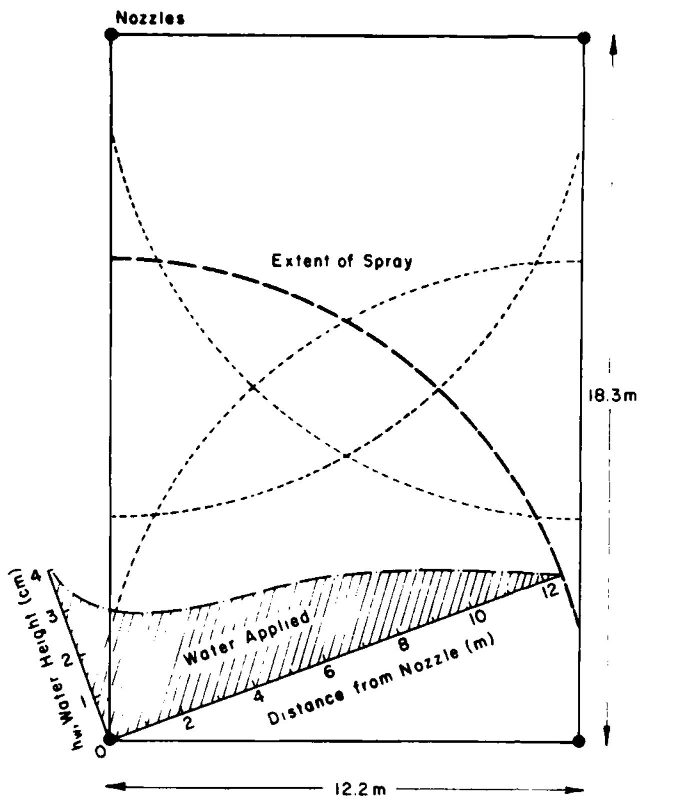


Figure 16. Spray pattern in area enclosed by four spray nozzles.

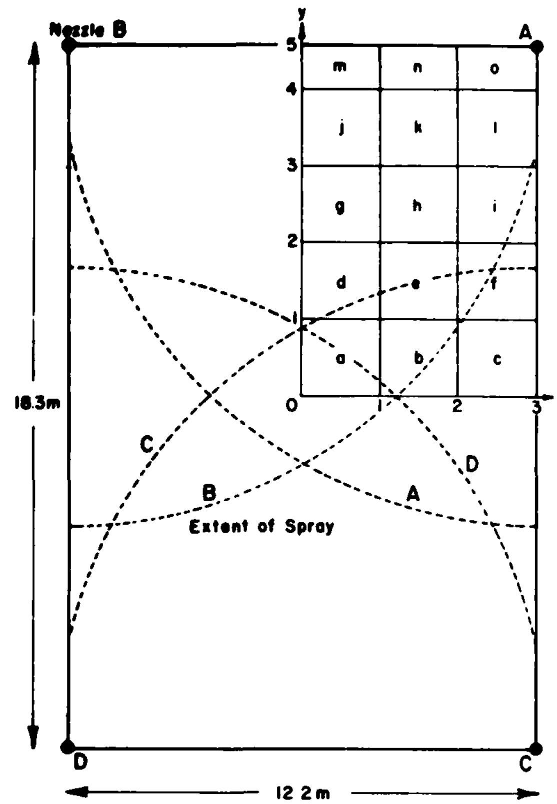
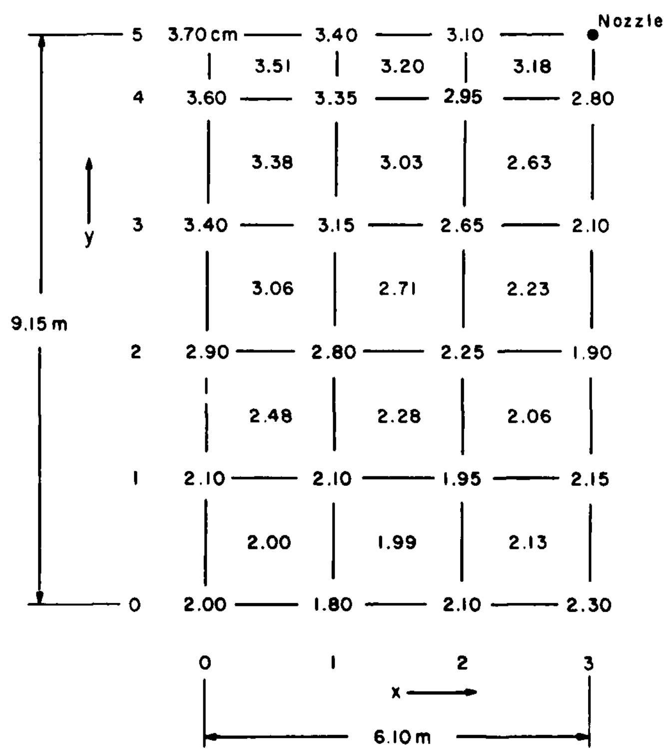


Figure 17. Grid system for calculating height of water applied.



Mean applied = 2.72 cm	Percent of applied
(Application Nos. 7,8,9)	80% = 2.18 cm
	90% = 2.45 cm
Mean from calculated grid	100% = 2.72 cm
center values = 2.66 cm	110% = 2.99 cm
	120% = 3.26 cm
Δh_w = 0.06 cm = 2.2%	130% = 3.54 cm

Figure 18. Calculated height of water applied in the grid system.

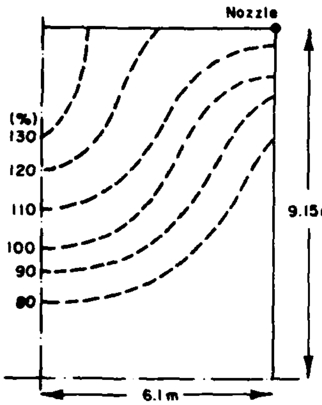


Figure 19. Water distribution contour map.

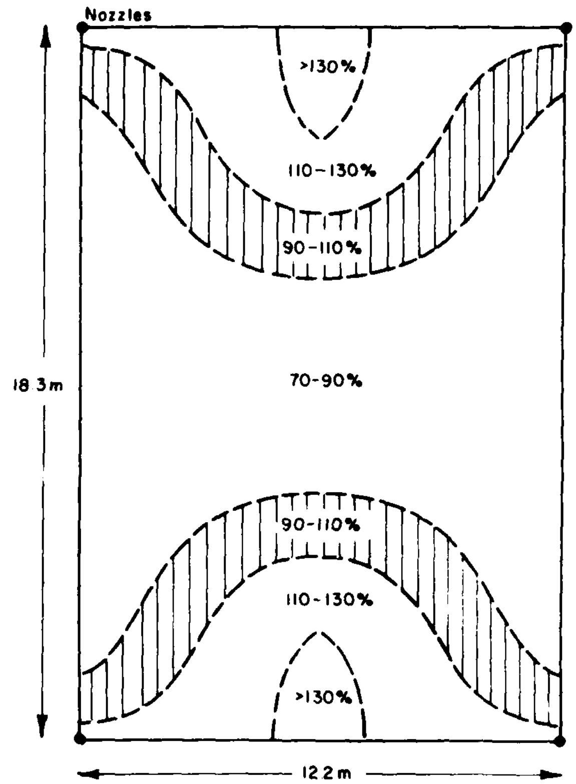


Figure 20. Calculated water distribution in percentage of mean applied (numbers indicate percentage of applied).

this analysis and the actual known mean amount of water applied is exceptionally good.

By interpolating the data shown in Figure 18, a water distribution "contour map" was drawn on the grid area, the contour lines being in terms of percentages of the mean amount of water applied (Fig. 19). Transferring the contour lines to the other three-quarters of the rectangle resulted in a contour map as shown in Figure 20.

This analysis indicates that relatively small sections, approximately 25% of the total area, receive an amount of water which is within ±10% of the mean amount applied (shaded areas in Fig. 20). Almost half (45%) of the middle area of each four-nozzle rectangle receives only 70 to 90% of the mean amount applied, and approximately 30% of the area, located at the ends of each rectangle, receives 110 to 130% (or more) of the mean applied. Therefore, certain locations in the sprayed field may receive almost twice as much water as certain other locations.

Figure 20 was developed from data obtained from only one nozzle during three applications (nos. 7, 8 and 9), using a collection bucket arrangement as shown in Figure 5. The data from this one nozzle were extrapolated to calculate the combined effect of four nozzles with overlapping spray.

During application 6, the water distribution data were obtained from the entire four-nozzle rectangle, using a bucket arrangement as shown in Figure 4. In this case, the data represent the actual combined effect from all four nozzles (Table 7).

A comparison between the two sets of data is shown in Figure 21. The amounts of water in each bucket after application 6, expressed in terms of percentages of the known mean amount applied, are shown according to their locations within the rectangle. The agreement with the previously developed water distribution map (percentage values shown in boxes) is reasonably good, except in the SE section of the rectangle.

The mean of the observed values was 2.41 cm; the known mean amount applied was 2.63 cm, resulting in a discrepancy of 0.22 cm or 8%. The discrepancy in the previous one-nozzle analysis was 2.2% (Fig. 18). Some of this discrepancy

Table 6. Water distribution on grid.

Nozzle:	A		B		C		D		Total
Coord. pt. (x,y)	Dist (m)	h_w (cm)	Dist (m)	h_w (cm)	Dist (m)	h_w (cm)	Dist (m)	h_w (cm)	h_w (cm)
0,0	11.0	0.50	11.0	0.50	11.0	0.50	11.0	0.50	2.00
1,0	10.0	0.85	12.3	0.05	10.0	0.85	12.3	0.05	1.80
2,0	9.4	1.05			9.4	1.05			2.10
3,0	9.1	1.15			9.1	1.15			2.30
0,1	9.4	1.05	9.4	1.05					2.10
1,1	8.2	1.40	10.9	0.55	11.9	0.15			2.10
2,1	7.5	1.60	12.4	0	11.4	0.35			1.95
3,1	7.1	1.70			11.1	0.45			2.15
0,2	8.0	1.45	8.0	1.45					2.90
1,2	6.6	1.80	9.6	1.00					2.80
2,2	5.6	1.90	11.4	0.35					2.25
3,2	5.2	1.90							1.90
0,3	6.9	1.70	6.9	1.70					3.40
1,3	5.2	1.90	8.7	1.25					3.15
2,3	3.8	2.05	10.7	0.60					2.65
3,3	3.2	2.10							2.10
0,4	6.3	1.80	6.3	1.80					3.60
1,4	4.3	2.00	8.3	1.35					3.35
2,4	2.4	2.20	10.3	0.75					2.95
3,4	1.1	2.75	12.3	0.05					2.80
0,5	6.1	1.85	6.1	1.85					3.70
1,5	4.1	2.00	8.1	1.40					3.40
2,5	2.1	2.30	10.1	0.80					3.10
3,5	0	3.75	12.2	0.10					3.85

Table 7. Water distribution from four nozzles (application 6, total applied = 2.63 cm).

Bucket	h_w (cm)	Percentage of total applied
1	2.57	98
2	2.54	97
3	2.32	88
4	2.13	81
5	2.04	78
6	1.39	53
7	1.95	74
8	2.79	106
9	2.49	95
10	2.29	87
11	2.55	97
12	2.14	81
13	3.53	134
14	3.22	122
15	2.49	95
16	2.15	82
17	2.54	97
18	2.98	113
19	3.21	122
20	1.47	56
21	1.92	73
Mean	2.41	92

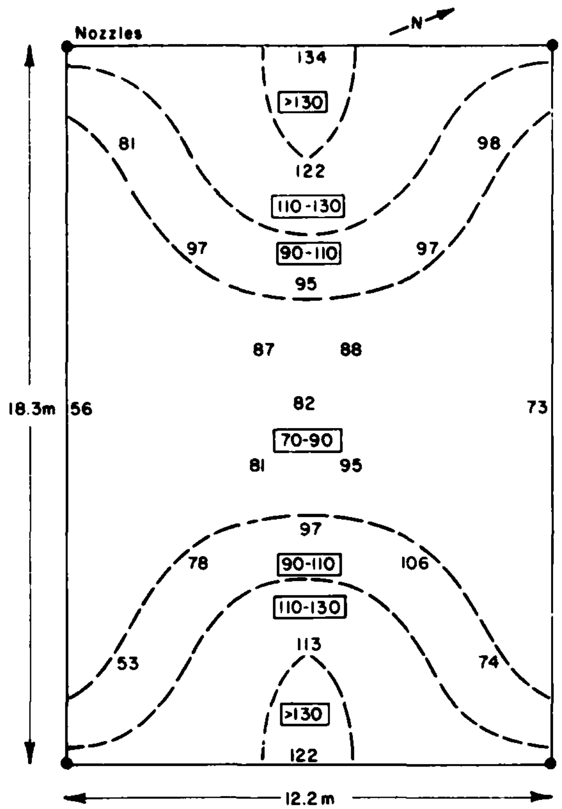


Figure 21. Observed water distribution (appl. 6) compared with calculated distribution (numbers indicate percentage of applied).

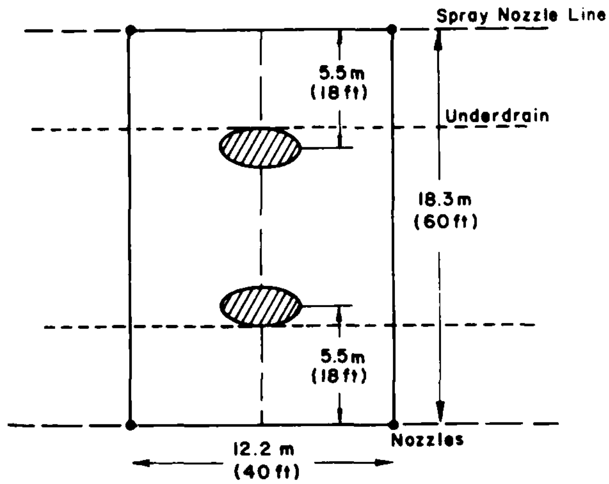


Figure 22. Location of preferred water content measurement areas.

could be attributed to evaporation during and shortly after the spraying, as the water amount measurements were usually completed within 1 or 2 hr after the applications.

The water distribution analysis results strongly indicate that the locations of field measurements, required for determining the hydraulic characteristics of a land treatment area during and after applications, can be of great importance if there are significant variations in the areal distribution of the applied water. Since water content measurements have been obtained at random locations in the treatment area, it is not surprising that sometimes the data have not reflected the amount of water applied on the field as a whole. Frequently it has not been possible to calculate a realistic mass water budget after an application because of unrepresentative water content data.

If accurate water content data are to be obtained for water budget determinations of the entire area, it is imperative that the data be obtained in those areas where the amount of water deposited on the terrain surface is approximately equal to the actual mean amount applied.

Based on the water distribution data obtained during four applications, it is possible to select locations where the probability of obtaining representative water content measurements is much better than that of purely random measurement locations. In this case, the most representative locations in any rectangle enclosed by four spray nozzles are those shown in Figure 22 as shaded areas. Any change in the distances between nozzles, their height above the ground, or the type of spray nozzles used, as well as any variation in speed or direction of the wind, would change the location of the preferred observation or measurement areas.

Underdrain flow

When drainage flow rate data are plotted vs time on arithmetic scales, the result is a skewed, bell-shaped curve (Abele et al. 1979). Ordinarily it is not obvious if such a curve can be described with a mathematical expression so that the cum-

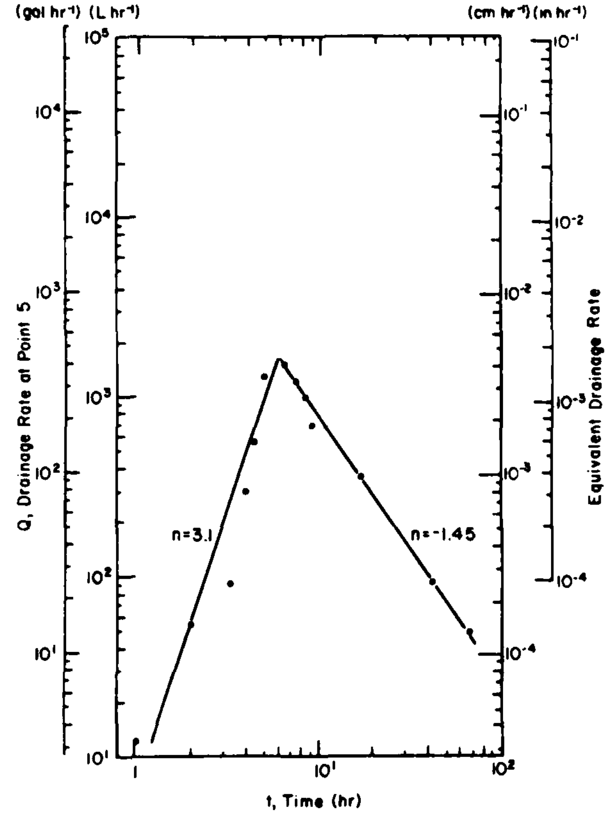


Figure 23. Drainage rate vs time (appl. 2).

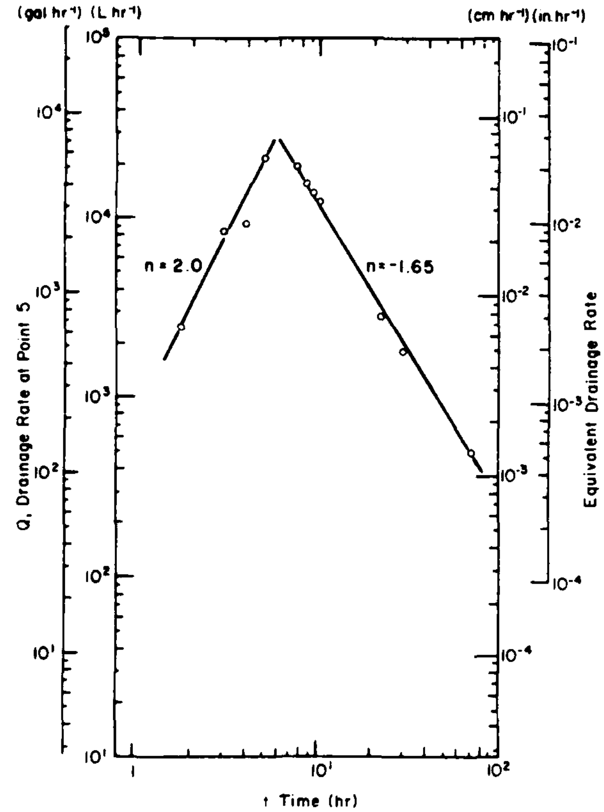


Figure 24. Drainage rate vs time (appl. 3).

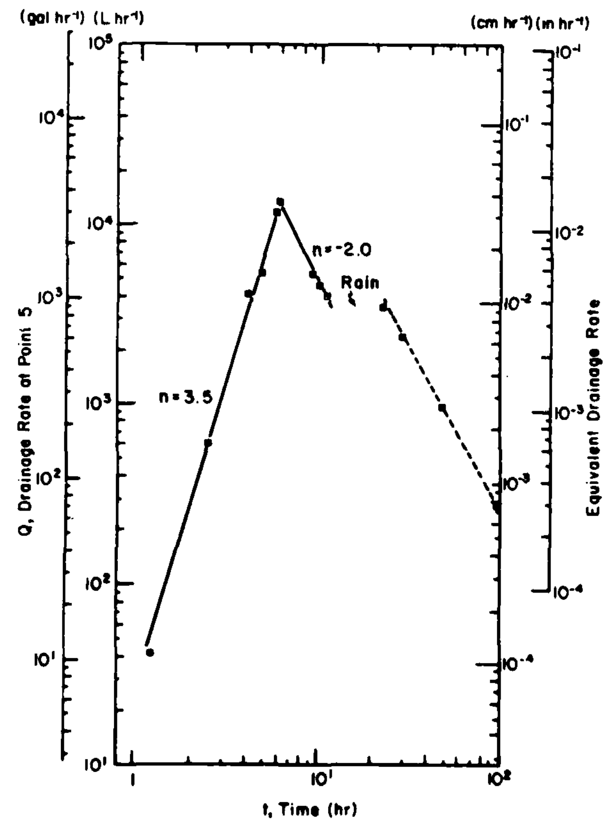


Figure 25. Drainage rate vs time (appl. 4).

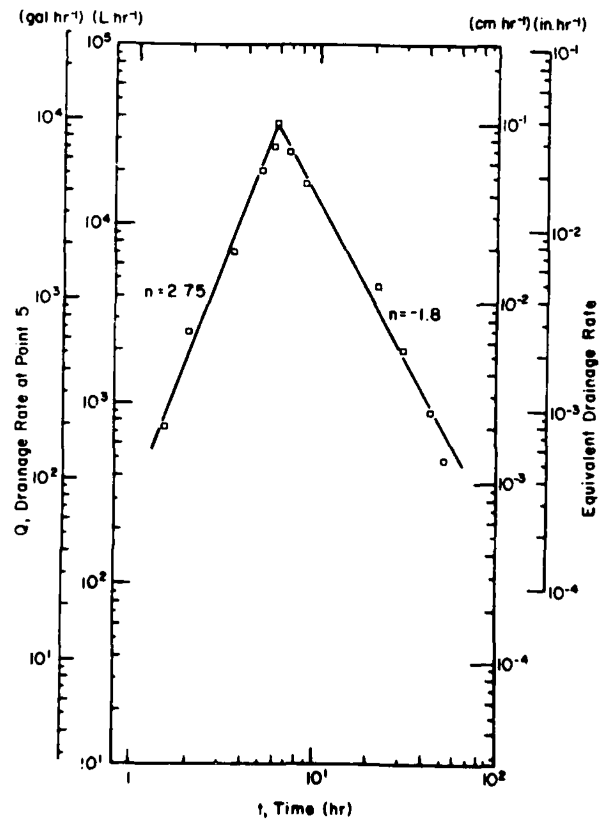


Figure 26. Drainage rate vs time (appl. 5)

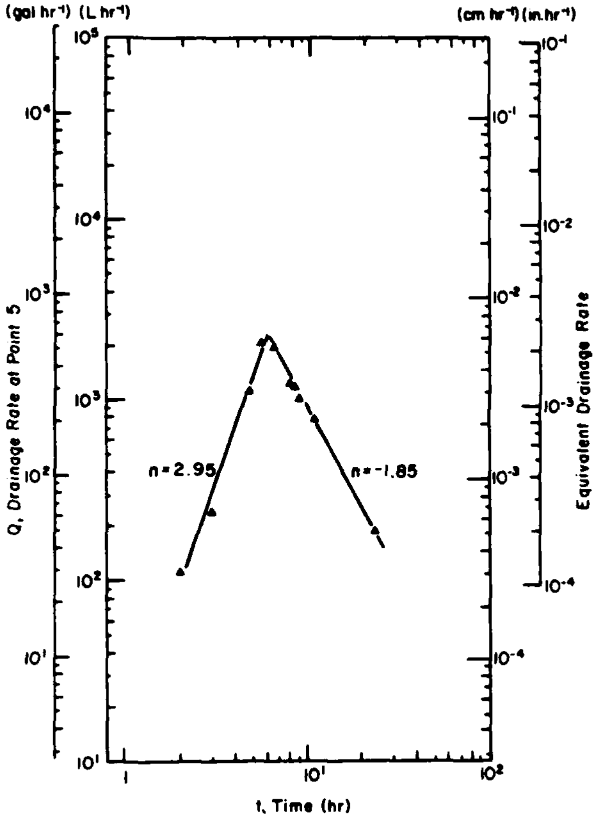


Figure 27. Drainage rate vs time (appl. 6).

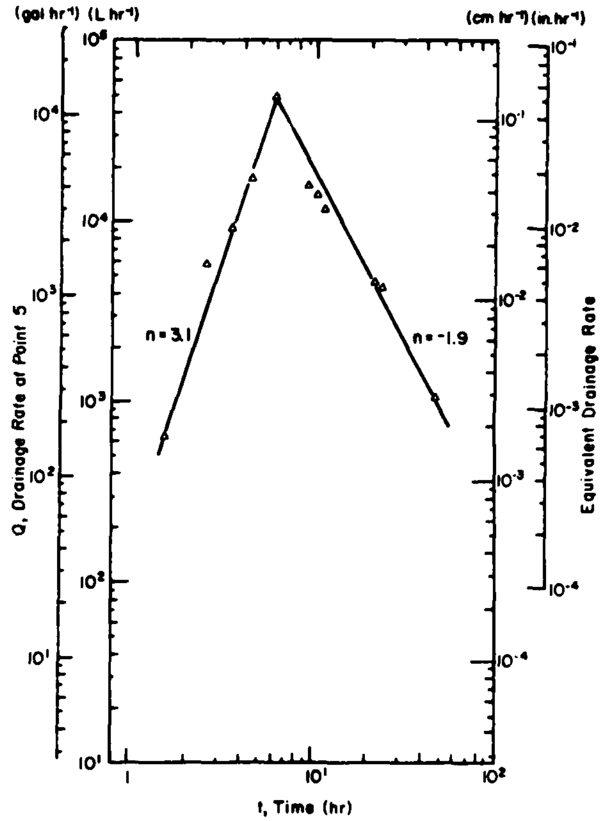


Figure 28. Drainage rate vs time (appl. 7).

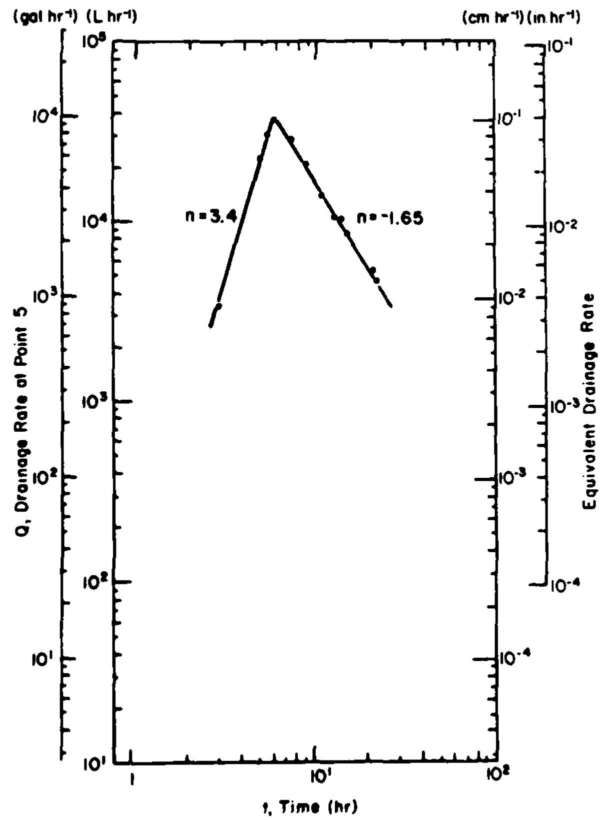


Figure 29. Drainage rate vs time (appl. 8).

ulative drainage at any time during or after wastewater application can be calculated. During the data analysis it was discovered that very frequently the drainage rate Q vs time t relationship could be represented by straight lines on a log-log plot. The value of Q usually increased approximately as the cube of time up to the peak flow rate point and then decreased approximately as the reciprocal of time squared.

The general expressions for the drainage rates with time are

$Q_1 = A_1 t^{n_1}$ (before peak flow rate reached) (11)

$Q_2 = A_2 t^{n_2}$ (after peak flow rate reached) (12)

where Q = drainage rate
t = time
A = intercept at t = 1
n_1 = slope before Q_{max} (positive)
n_2 = slope after Q_{max} (negative).

The Q vs t data (Table A4) for applications 2-10 are plotted on log-log scales in Figures 23-31. (No drainage data were obtained during the first application.) Figures 32 and 33 show the data obtained from two applications during the

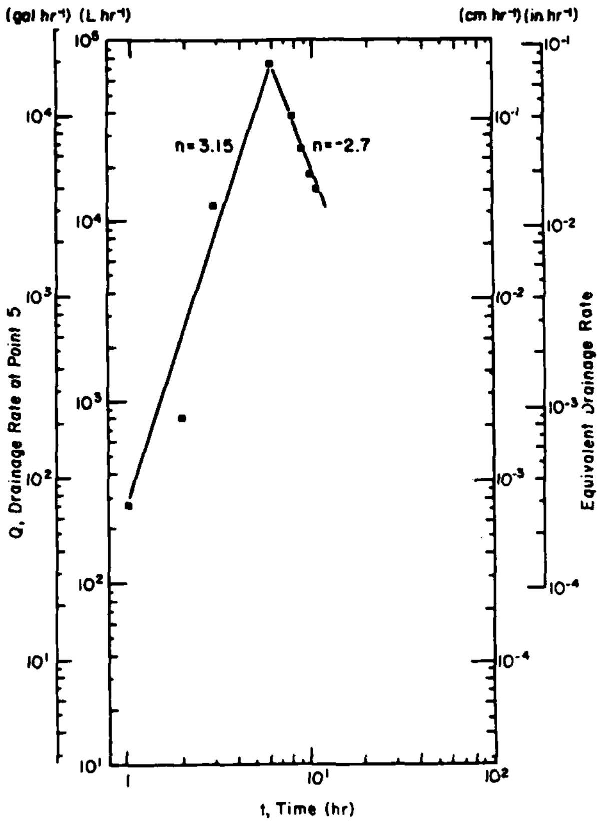


Figure 30. Drainage rate vs time (appl. 9).

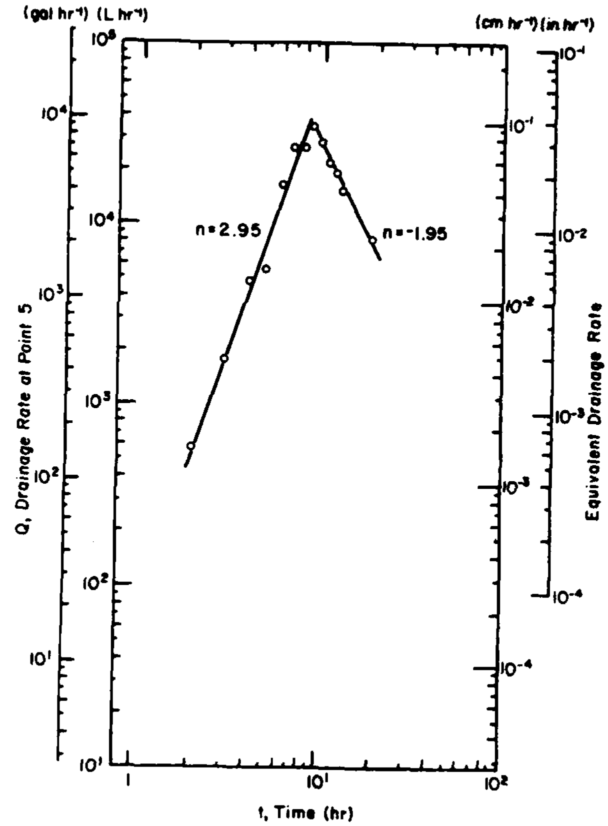


Figure 31. Drainage rate vs time (appl. 10).

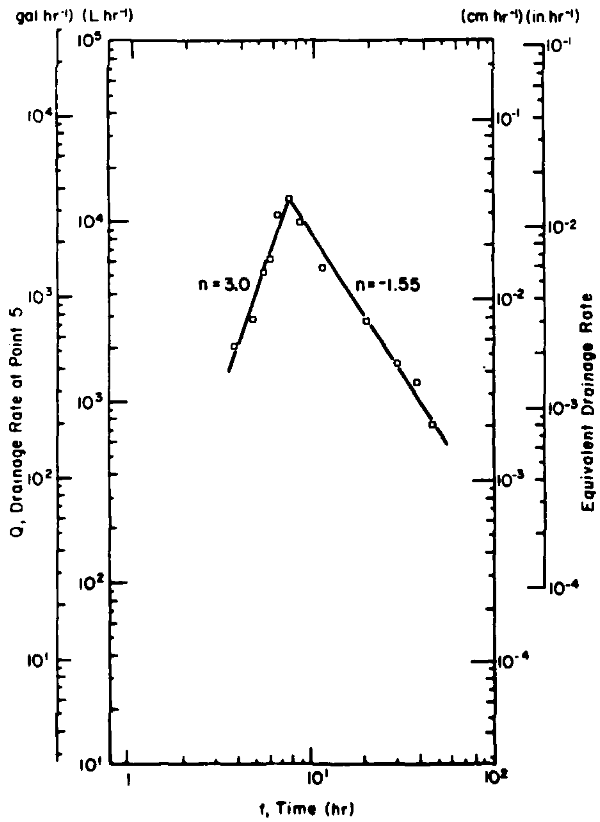


Figure 32. Drainage rate vs time (appl. 7, 1978).

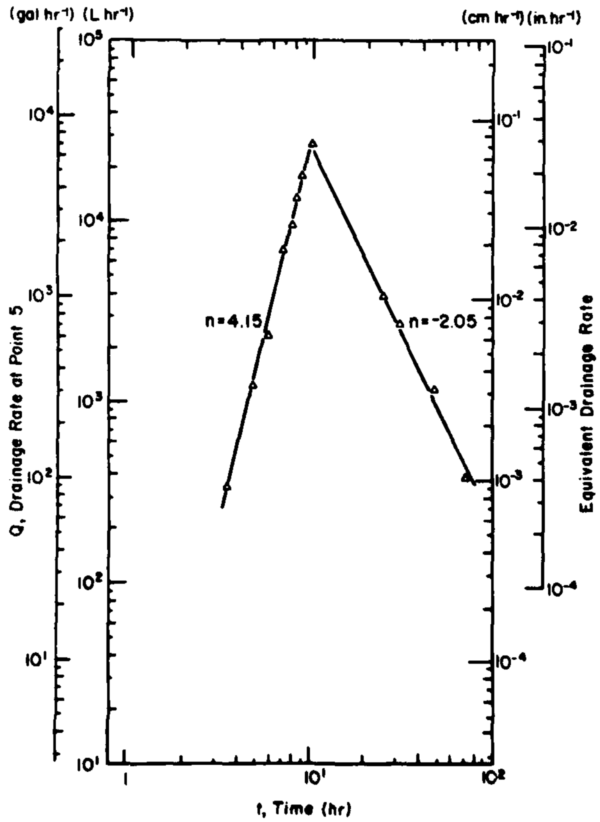


Figure 33. Drainage rate vs time (appl. 9, 1978).

Table 8. Drainage rate characteristics.

Applic.	Q vs t slopes		$Q_{(max)}$
	n_1	n_2	$(L\ hr^{-1})$
2	3.1	-1.45	1,700
3	2.0	-1.65	29,000
4	3.5	-2.0	13,200
5	2.75	-1.8	37,000
6	2.95	-1.85	2,300
7	3.1	-1.9	47,000
8	3.4	-1.65	39,000
9	3.15	-2.7	75,000
10	2.95	-1.95	37,000
7(1978)	3.0	-1.55	13,000
9(1978)	4.15	-2.05	26,000

1978 season. The slopes of the lines and the peak flow values are summarized in Table 8.

There were similarities between certain applications, based primarily on the peak flow rates and, therefore, between amounts of cumulative drainage after a particular time period. It was apparent that the drainage rate was influenced by the initial water content conditions of the soil prior to application. Higher initial water contents resulted in higher drainage rates.

For the two applications (nos. 2 and 6) that produced low peak drainage rates (1,600 and 2300 L hr⁻¹), the mean initial volumetric water content V_w in the top 40 cm (16 in.) was 28.8%, the saturation S being 69.2%. For application 4, with a peak rate of 13,500 L hr⁻¹, the V_w and S values were 31.9% and 76.7%, respectively. For applications with the high drainage rates (nos. 3, 5, 7 and 8; 28,000 to 48,600 L hr⁻¹) the mean V_w and S values were 33.9% and 81.5%, respectively. (No water content data were available for application 9; the peak flow was 75,000 L hr⁻¹.)

When the data from the continuous applications with high drainage rates were plotted together, it was possible to enclose all the data points within a relatively narrow envelope having a slope of 3 before the peak flow was reached and a slope of -2 after peak flow (Fig. 34). The peak flow for these, as well as for the other continuous applications, occurred approximately 1 hr after the end of application.

The data were separated into groups according to convenient time intervals; the mean values (and the range) of each group are plotted in Figure 35. The lines with slopes of 3 and -2 agree reasonably well with the actual data. (A regression analysis would very likely result in slightly different slopes, but in this case little would be gained from a strict statistical approach which would make the computation of drainage rates and cumulative intake more cumbersome be-

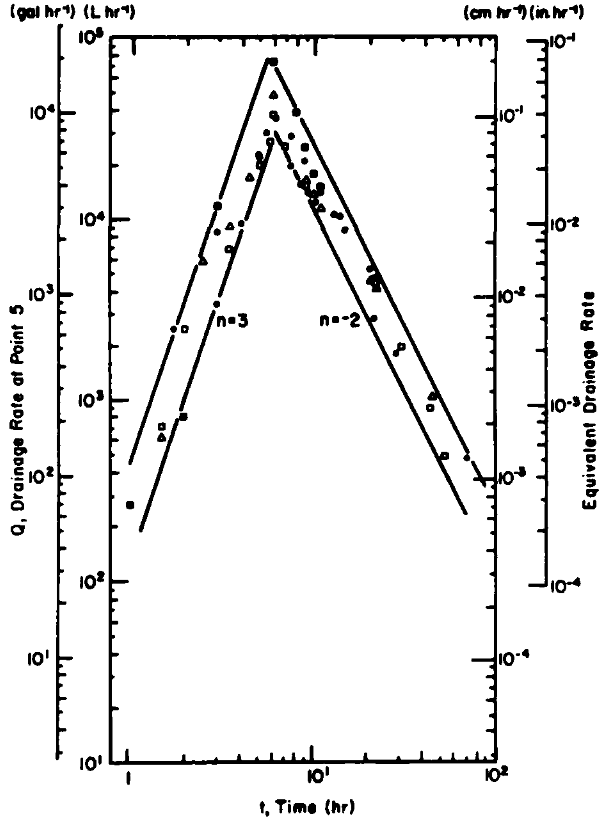


Figure 34. Drainage rate vs time (appl. 3, 5, 7, 8 and 9).

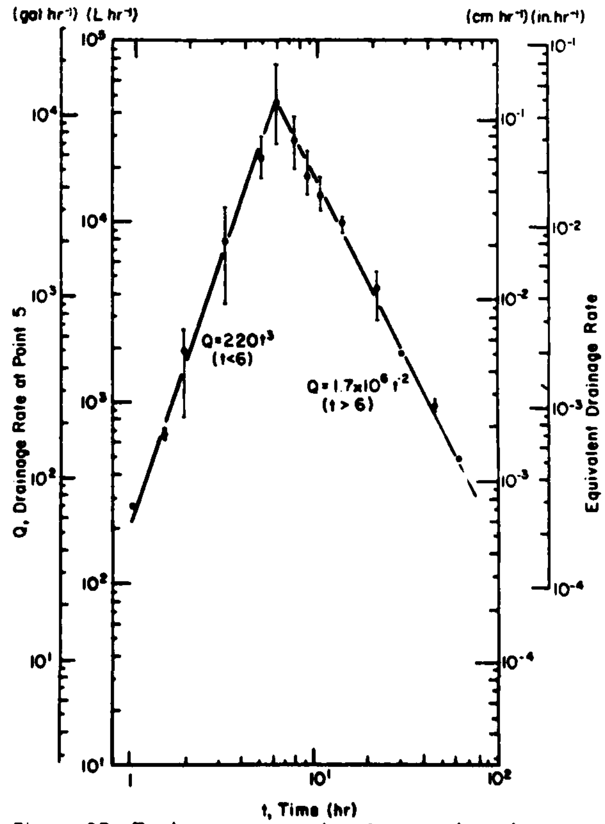


Figure 35. Drainage rate vs time (mean of appl. 3, 5, 7, 8 and 9).

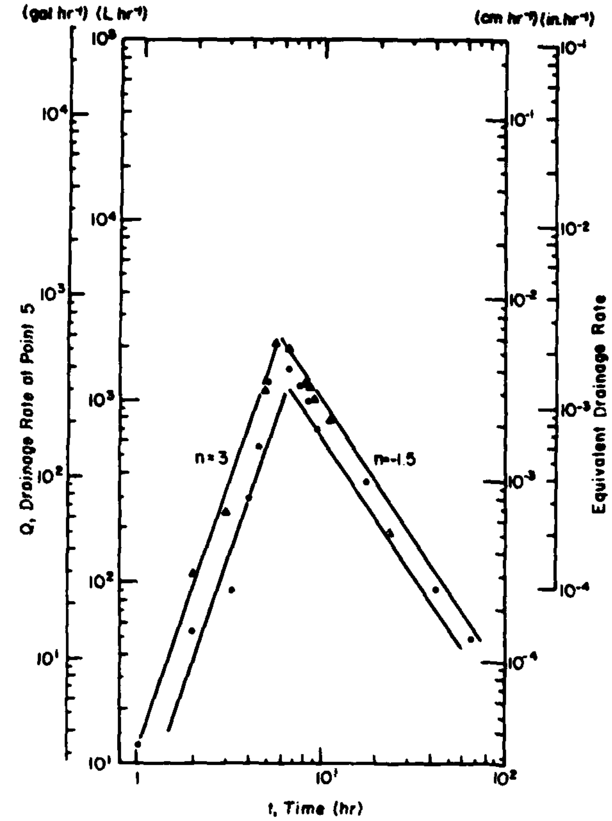


Figure 36. Drainage rate vs time (appl. 2 and 6).

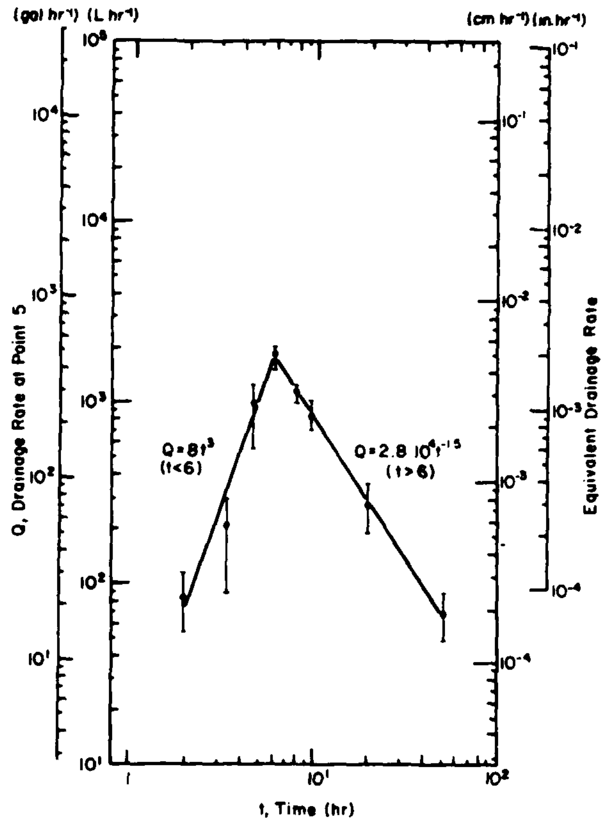


Figure 37. Drainage rate vs time (mean of appl. 2 and 6).

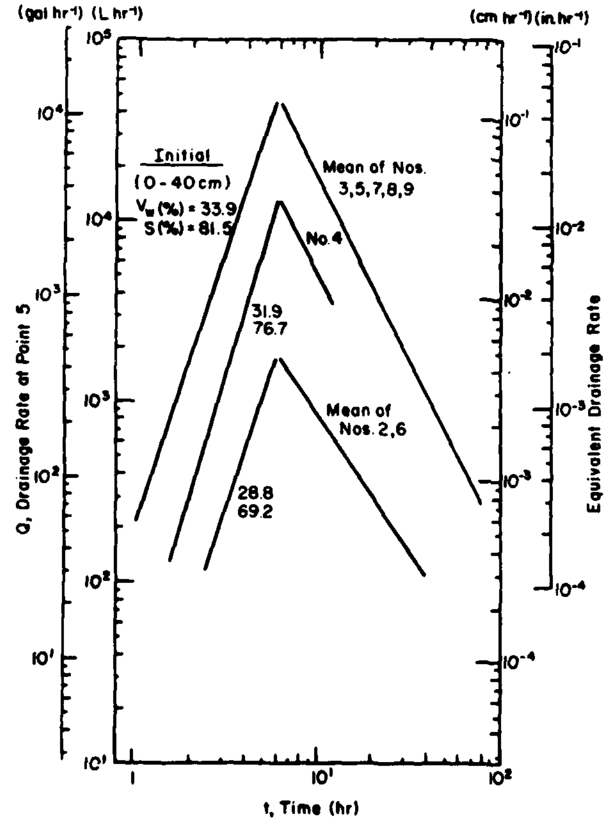


Figure 38. Drainage rate vs time (mean of continuous applications).

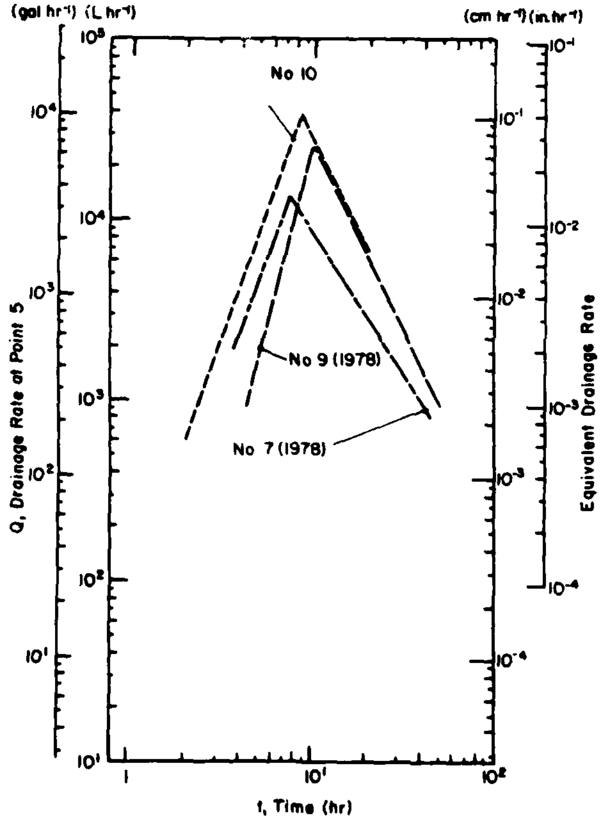
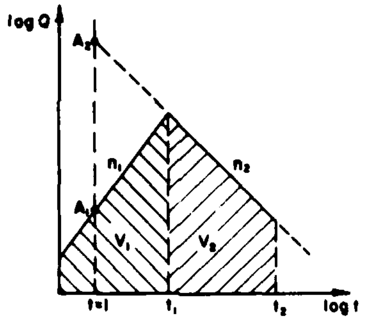


Figure 39. Drainage rate vs time (intermittent applications).



$$Q_1 = A_1 t^{n_1} \quad (t < t_1;\ n_1 = \text{positive})$$

$$Q_2 = A_2 t^{n_2} \quad (t > t_1;\ n_2 = \text{negative})$$

$$V = V_1 + V_2 = \int_{t=0}^{t_1} Q_1\,dt + \int_{t_1}^{t_2} Q_2\,dt$$

Figure 40. Computation of cumulative drainage from drainage rate.

cause of inconvenient exponents in the equations.)

The combined data from the two continuous applications with the low drainage rates are plotted in Figure 36. An envelope with a slope of 3 for the data prior to peak flow also appears to be reasonably appropriate in this case. However, for the data after the peak flow point, the slope of the envelope in this case is less steep: a slope of −1.5 agrees well with the data. The mean values and range of grouped data for the low drainage rate applications are plotted in Figure 37.

Drainage data from application 4, which produced medium flow rates, were shown earlier in Figure 25. In this case, the slopes were 3.5 and −2. Rain occurred several hours after the application. The slope of the Q vs t line after the rainfall was similar to that prior to the rainfall, although the location of the line, as would be expected, was shifted to the right due to the increased drainage.

A comparison of the results between the three groups of data (high, medium and low drainage rates) is shown in Figure 38.

The Q vs t relationship from the three intermittent applications (no. 10, 1979; no. 7 and 9, 1978) is shown in Figure 39 (refer to Fig. 31, 32, 33). The peak flow rates occur at approximately the time when the application was completed and correspond approximately to the continuous application peak flow time 1 hr after application. Therefore, the drainage rate increases with time during water application until the application stops, regardless of whether a specific amount of water is applied continuously for 5 hr or intermittently for 6.5 or 10 hr.

The equations for calculating the mean drainage rate Q at any time t are summarized in Table 9 *(refer also to Fig. 35 and 37).*

Computation of the cumulative amount of water drained at any time involves integrating

Table 9. Equations for drainage rate Q (L hr⁻¹) and cumulative drainage V(L); time t = hr.

Continuous applications

Mean of applications 3,5,7,8, and 9

$Q(t < 6) = 220\,t^{3}$	(18)
$Q(t > 6) = 1.7 \cdot 10^{6}\,t^{[illegible]}$	(19)
$V(t < 6) = 55\,t^{4}$	(20)
$V(t > 6) = 355 \cdot 10^{[illegible]} - 1.7 \cdot 10^{6}\,t^{[illegible]}$	(21)

Application 4

$Q(t < 6) = 25\,t^{3.5}$	(22)
$Q(t > 6) = 475 \cdot 10^{[illegible]}\,t^{[illegible]}$	(23)
$V(t < 6) = 5.6\,t^{4.5}$	(24)
$V(t > 6) = 97 \cdot 10^{[illegible]} - 475 \cdot 10^{[illegible]}\,t^{[illegible]}$	(25)

Mean of applications 2,6

$Q(t < 6) = 8\,t^{3}$	(26)
$Q(t > 6) = 28 \cdot 10^{[illegible]}\,t^{[illegible]}$	(27)
$V(t < 6) = 2\,t^{4}$	(28)
$V(t > 6) = 25.5 \cdot 10^{[illegible]} - 56 \times 10^{[illegible]}\,t^{[illegible]}$	(29)

Intermittent applications

Application 10

$Q(t < 8.5) = 60\,t^{3}$	(30)
$Q(t > 8.5) = 2.67 \cdot 10^{6}\,t^{[illegible]}$	(31)
$V(t < 8.5) = 15\,t^{4}$	(32)
$V(t > 8.5) = 392 \cdot 10^{[illegible]} - 2.67 \cdot 10^{6}\,t^{[illegible]}$	(33)

Application 7 (1978)

$Q(t < 7.5) = 31\,t^{3}$	(34)
$Q(t > 7.5) = 267 \cdot 10^{[illegible]}\,t^{[illegible]}$	(35)
$V(t < 7.5) = 7.7\,t^{4}$	(36)
$V(t > 7.5) = 219 \cdot 10^{[illegible]} - 534 \cdot 10^{[illegible]}\,t^{[illegible]}$	(37)

Application 9 (1978)

$Q(t < 10) = 2.6\,t^{4}$	(38)
$Q(t > 10) = 26 \cdot 10^{6}\,t^{[illegible]}$	(39)
$V(t < 10) = 0.5\,t^{5}$	(40)
$V(t > 10) = 310 \cdot 10^{[illegible]} - 26 \cdot 10^{6}\,t^{[illegible]}$	(41)

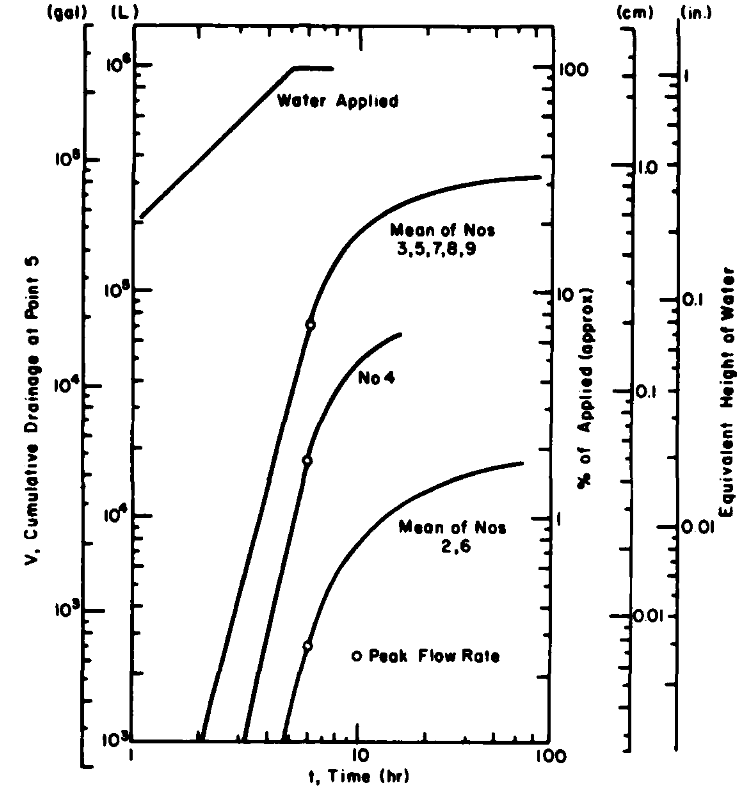


Figure 41. Cumulative drainage vs time (continuous applications).

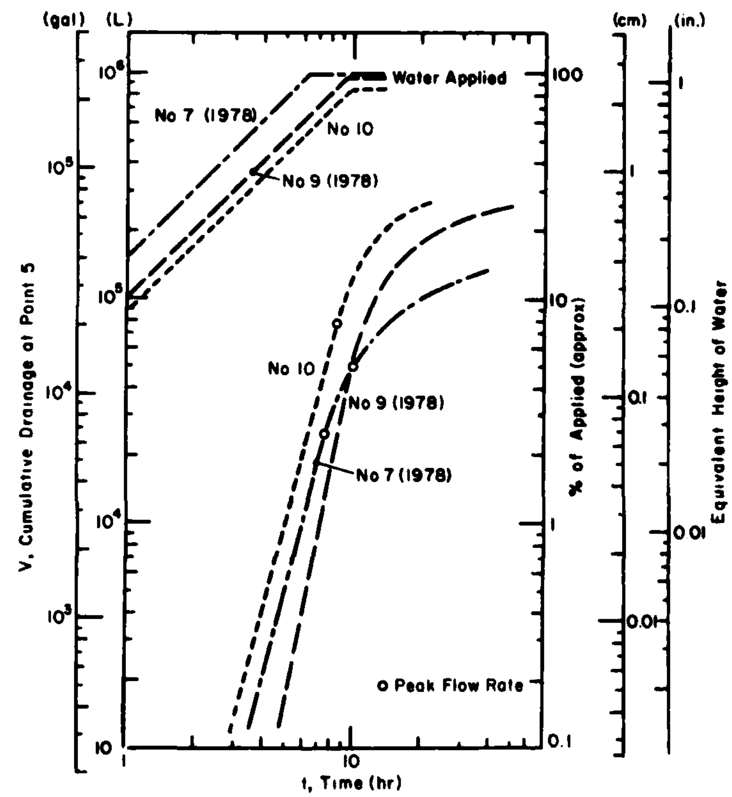


Figure 42. Cumulative drainage vs time (intermittent applications).

the area under the Q vs t curve. Therefore, the general expression for the cumulative drainage V is

$$V = \int_0^t Q\,dt. \tag{13}$$

Because of the shape of the area under the curve, which is a discontinuous function (Fig. 40), computation of V has to be done in two increments, V before the peak flow point (V_1) and after the peak (V_2):

$$V = V_1 + V_2 = \int_{t=0}^{t_1} Q_1\,dt + \int_{t_1}^{t_2} Q_2\,dt \tag{14}$$

where t_1 is the time at peak flow Q_{max} and t_2 any time after Q_{max}. Using eq 11 and 12

$$V_1 = \int_{t=0}^{t_1} A_1\,t^{n_1}dt \tag{15}$$

and

$$V_2 = \int_{t_1}^{t_2} A_2\,t^{n_2}\,dt. \tag{16}$$

Therefore, the total cumulative drainage at any time after the peak flow rate is

$$V = A_1(n_1+1)^{-1}\,t_1^{n_1+1}$$
$$+ A_2(n_2+1)^{-1}\,t_2^{n_2+1} - A_2(n_2+1)^{-1}\,t_1^{n_2+1}. \tag{17}$$

The equations for calculating the mean cumulative drainage V at any time t are summarized in Table 9. The calculated V vs t relationships are plotted in Figure 41 for the three groups of continuous applications and in Figure 42 for the three intermittent applications.

For mass water balance calculations the amount of water that has drained through the underdrain system at any time during and after the application can be either computed from the equations in Table 9 or determined from Figures 41 and 42.

The amount of cumulative drainage at any time after application can be estimated from the peak flow rate data. This has practical applications. For example, sometimes in the field it may be desirable to predict the amount of water that will have drained 1 day after the application. Since the peak flow rate is usually reached within 1 hour after the end of application, a prediction of the next day's approximate drainage (or even for 2 days after) can be made very shortly after the application is stopped.

Figure 43 shows the V vs Q_{max} relationship. The Q_{max} data points (Table 10) are from Figures 38 and 39 (or eq 18, 22, 26, 30, 34, and 39, Table 9) and the V data points from Figures 41 and 42 (or eq 20, 24, 28, 32, 36, and 40 for V at peak flow rate, and eq 21, 25, 29, 33, 37, and 41 for V at t = 24 hr). The y-axis scale on the right side of Figure 43 shows the cumulative drainage in terms of the approximate percentage of total water applied. For example, if the peak flow rate for an application was 10,000 L hr^{-1} (2640 gal. hr^{-1}), the cumulative drainage at the peak rate would be approximately 17,000 L (4500 gal.) or approximately 1.7% of the total applied, and after 1 day approximately 70,000 L (18,500 gal.) or approximately 7% of the total applied.

Figure 43 is an empirical, not an analytical, relationship, combining all the mean data from the continuous and the intermittent applications. The V vs Q_{max} relationship can be used for predicting the approximate cumulative drainage from wastewater application under typical conditions at the Deer Creek Lake land treatment facility.

The expressions for the two lines in Figure 43 are

$$V = 1.7\,Q_{(max)}\ \text{(at peak flow rate)} \tag{42}$$

$$V = 7\,Q_{(max)}\ \text{(after 1 day)}. \tag{43}$$

It should be noted that for the same Q_{max}, the V values for the intermittent applications are slightly higher than those for the continuous applications.

It is also possible to estimate the expected cumulative drainage from soil tension data obtained prior to water application h_0. Figure 44 shows the relationship between the mean cumulative drainage (at peak flow and after 1 and 2 days) and the mean initial soil tension (Table 10). For example, if the initial soil tension (mean for 0 to 80-cm depth) in the spray area prior to water application is approximately 200 (cm of water), the cumulative drainage at the time of peak flow will be in the vicinity of 15,000 L (4000 gal.). After one day it will be approximately 65,000 L (17,000 gal.), and after 2 days approximately 85,000 L (22,500 gal.), or less than 10% of the amount applied. In this case, most of the water will remain in the soil.

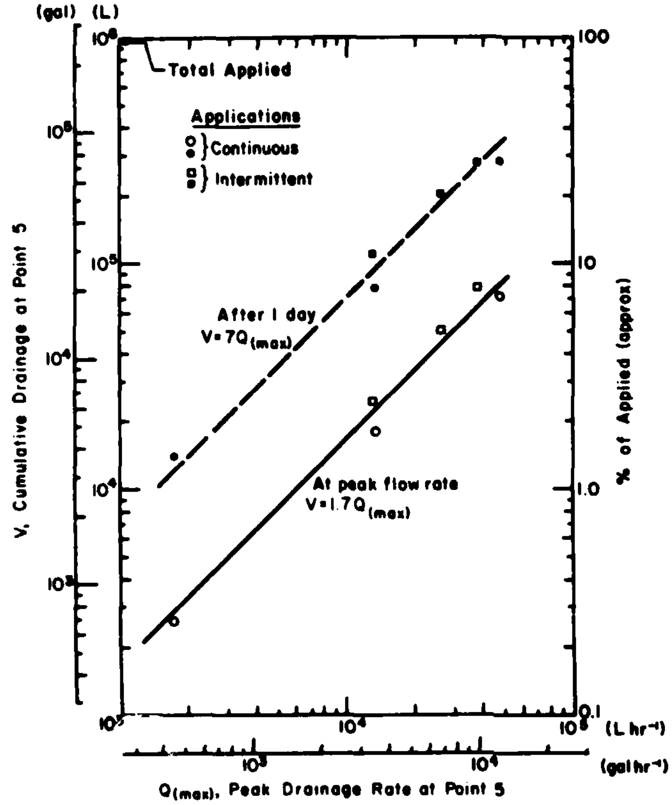


Figure 43. Cumulative drainage vs peak drainage rate.

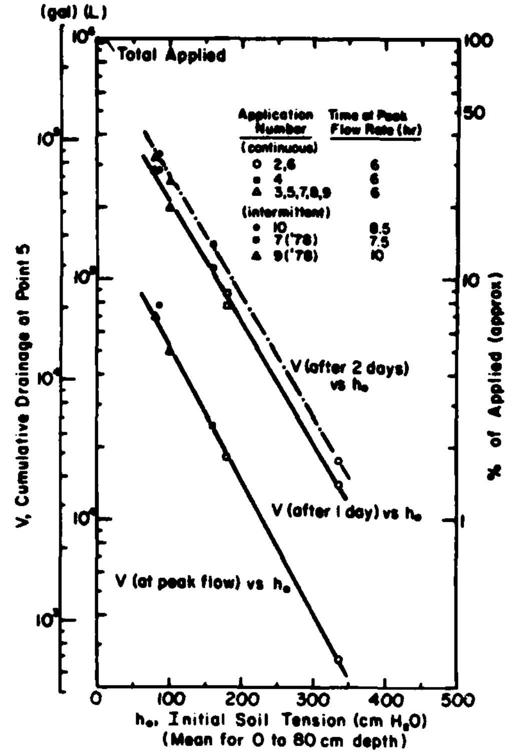


Figure 44. Cumulative drainage vs initial soil tension.

Table 10. Mean drainage and soil water data for application groups.

	Application no.					
	Continuous			Intermittent		
	2,6	4	3,5,7,8,9	10	7(1978)	9(1978)
t, Peak (hr)	6	6	6	8.5	7.5	10
Q, Peak (L hr⁻¹)	1,730	13,200	47,500	37,000	13,000	26,000
V Drained (L) peak	2,600	18,000	71,300	78,300	24,400	50,000
V Drained (L) 1 day	14,000	77,000	284,000	281,000	110,000	202,000
V Drained (L) 2 days	17,400	87,100	320,000	336,000	142,000	256,000
h_0, Initial tension (cm H_2O)	335	180	80	85	160	100
h, Tension at peak Q:	95	65	45	55	55	0
V_w, Initial (%) 0-40 cm	28.8	31.9	33.9			
V_w, Initial (%) 0-80 cm	29.8	29.4	30.6		27.2	
S, Initial (%) 0-40 cm	69.2	76.7	81.5			
S, Initial (%) 0-80 cm	72.2	71.2	74.1		65.9	

Extrapolating the lines in Figure 44 towards the y axis gives an indication of what the V values may be for a saturated soil condition ($h_0 = 0$). The intercepts for the 1- and 2-day lines indicate that the amount of water drained 1 to 2 days after water application would be equivalent to 70 to 85% of the total applied. The total evapotranspiration (ET) for this time period would be in the 20 to 30% range.

This analysis leads to a conclusion that for a saturated (or nearly saturated) soil condition, it will probably take a day or more for the total amount of water drained and lost due to ET to be approximately equivalent to the total amount applied.

It should be noted that there are no data to

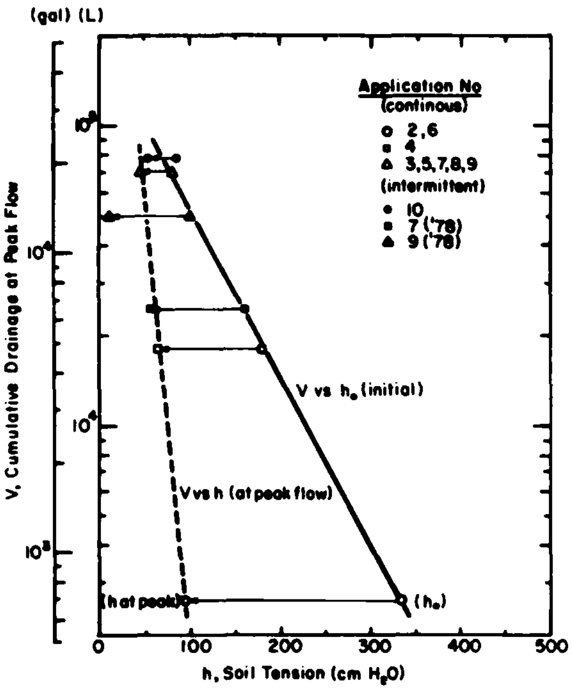


Figure 45. Cumulative drainage of peak flow vs soil tension (initial and at peak flow).

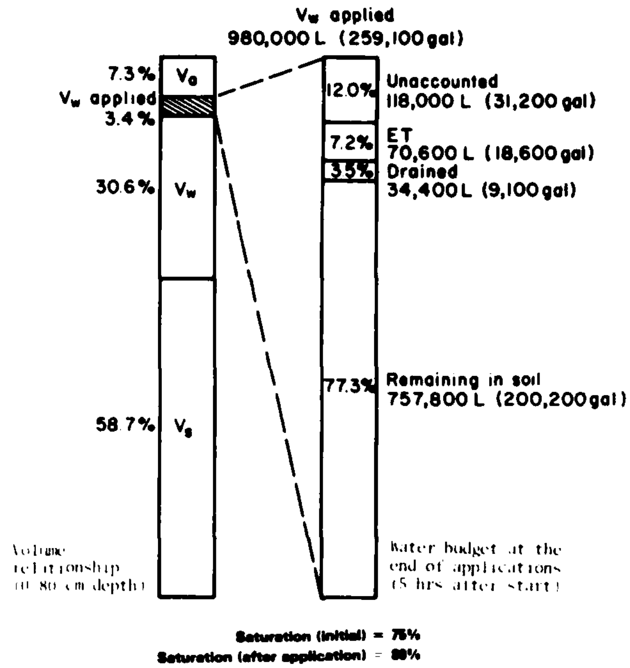


Figure 46. Water budget (mean of appl. 3, 5, 7, 8 and 9).

support this conclusion, which was based on extrapolation. It is possible for a saturated soil condition that the V (drained) + $ET \approx V$ (applied) state can occur earlier than after 1 day. Since it is unlikely that applications on agricultural fields would be made when the soil is already saturated, the drainage characteristics during a saturated condition may be of only academic interest in this case, but may be of considerable interest where soil is used solely for land treatment of wastewater, not crop growth. The infiltration test, discussed earlier, indicated that 2.6 cm of water (a typical application) can percolate into the saturated soil in a time period of 5 to 8 hr (Fig. 11).

Figure 45 shows the decrease in soil tension at the peak flow rate in comparison with the initial tension. The solid line relates the cumulative drainage at peak flow with the initial soil tension (from Fig. 44). The dashed line relates the cumulative drainage with the soil tension, both occurring at the time when the peak flow was reached. The arrows indicate the decrease in soil tension during the 6- to 10-hr period.

Water budget

The water budget for a typical continuous application, represented by the mean data from applications 3, 5, 7, 8 and 9 at the end of 5 hr was calculated and the results shown in Figure 46.

Initial soil conditions (0–80 cm):

Specific gravity G_s	= 2.71
Dry density of soil γ	= 1.59 g cm^{-3}
Volume of solids V_s	= 58.7%
Volume of voids V_v	= 41.3%
Volumetric water content V_w	= 30.6%
Saturation S	= 74% (81.5% for 0 to 40 cm)
Volume of water applied V_W	= 980,000 L (259,100 gal.) = 2.69 cm (1.06 in.)

Total volume of field:

$$V_T \text{ (3.64 ha, 80 cm deep)} = 29{,}144{,}500 \text{ L } (7{,}700{,}000 \text{ gal.}).$$

Therefore,

$$V_W \text{ (applied)} \approx 3.4\% \text{ of } V_T .$$

Soil conditions after application:

Volumetric water content, $V_w = 33.2\%$

Increase in V_w, $\Delta V_w = 2.6\%$

Saturation, $S = 80\%$ (84% for 0–40 cm).

Volume of water remaining in soil:

$$V_W \text{ (soil)} = V_T \times \Delta V_w$$
$$= 29{,}144{,}500 \times 0.026$$
$$= 757{,}800 \text{ L } (200{,}200 \text{ gal.}).$$

Volume of water drained (from eq 20 or Fig. 41):

$$V\text{(drained)} = 55\, t^4 = 55(5)^4$$
$$= 34{,}400 \text{ L } (9{,}100 \text{ gal.}).$$

The mean net pan evaporation during the five application days was 0.73 cm per day. If one takes 80% of the pan evaporation as the daily ET and assumes that approximately 30% of the daily ET occurred during the 5-hr application period, then the calculation will result in an estimated ET value of 7.2%:

$$ET = V_W \text{ (applied)} \times 0.072$$
$$= 70{,}600 \text{ L } (18{,}600 \text{ gal.}).$$

The water budget, including the percentage of applied, for the test site can be summarized as follows:

V_W (soil)	= 757,800 L	(200,200 gal.)	77.3%
V (drained)	= 34,400 L	(9,100 gal.)	3.5%
ET	= 70,600 L	(18,600 gal.)	7.2%
Total	= 862,800 L	(227,900 gal.)	88.0%
Unaccounted	= 118,000 L	(31,200 gal.)	12.0%

Therefore, at the end of the 5-hr application it was possible to account for 88% of the water applied. As discussed in a previous report (Abele et al. 1979), an error or a variation of only 0.1% in the volumetric water content is equivalent to 3% of the total water applied. Consequently, a change in the V_w of only a fraction of 1% and an error of a few percent in estimating the ET could easily account for the remaining 12% of the water.

SUMMARY AND CONCLUSIONS

During June, July and August of 1979, a total of 10 wastewater applications, each nearly 1 million L (nearly 260,000 gal.), were made over an area of 3.64 ha (9 acres), the corresponding height of water being approximately 2.7 cm (slightly over 1 in.) per application.

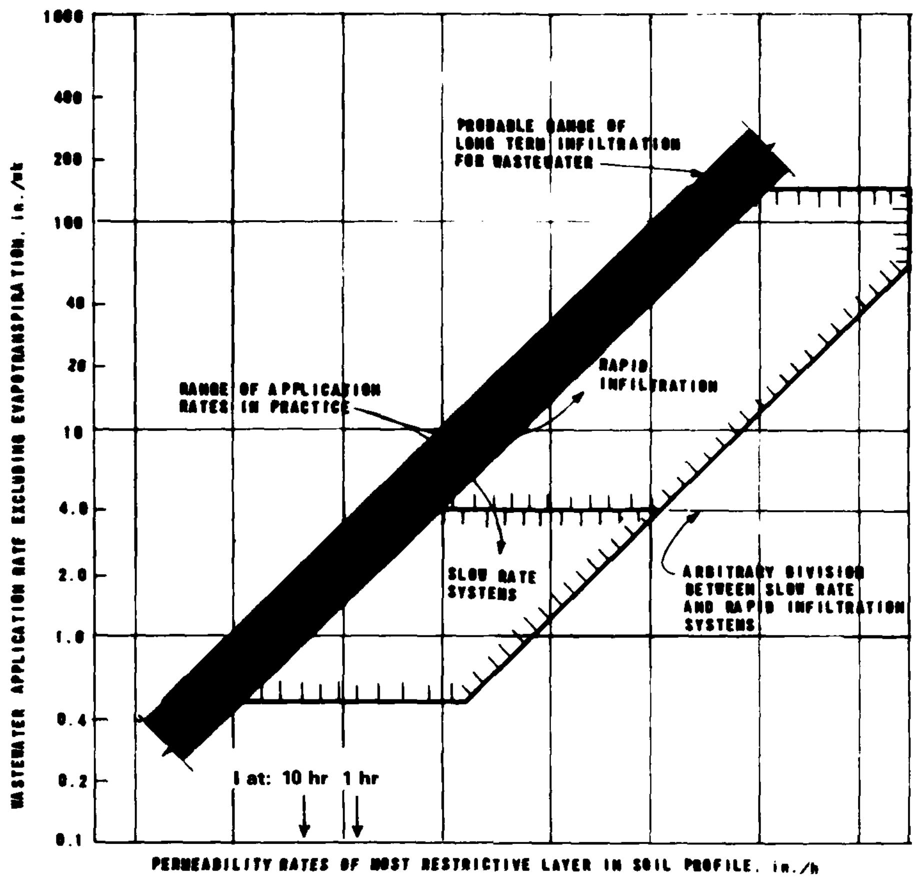
From a large-scale in-situ infiltration test, it was determined that the infiltration rate for a saturated soil condition at this site varied from moderately slow (less than 1 cm hr^{-1} during the first hour) to slow (0.3 cm hr^{-1} after 12 hr) and could be expressed by $I = 0.62\, t^{-0.26}$ cm hr^{-1}. For an unsaturated soil condition (initial $S = 82\%$), the mean infiltration rate during the first hour was approximately 2 cm hr^{-1}.

According to the current design criteria (Fig. 3-3 in EPA/COE 1977, reproduced here as Fig. 47), the wastewater application rate could be increased to at least 5 cm (2 in.) and probably to as much as 10 cm (4 in.) per week. (Figure 47 shows the I values at 1 and 10 hr for this site.) Therefore, a 2.5-cm (1-in.) application, requiring a period of 5 hr for a continuous application, could be done every second or every third day, the actual scheduling depending on rainfall. The criterion shown in Figure 47 does not include the effects from evaporation and precipitation. For example, a high precipitation rate relative to evaporation would suggest a decrease in the design application rate, and vice-versa. The mean daily precipitation and pan evaporation rates for June, July and August 1978 and 1979 were 0.36 cm (0.14 in.) and 0.59 cm (0.23 in.), respectively (see Table 6 in Abele et al. 1979 and Table A1). Since the evaporation rate exceeds the precipitation rate, no decrease in the design mean weekly application rate, due to rainfall, would be required.

The water distribution on the ground during spray application was not uniform; some locations received less than 70% and others more than 130% of the mean amount applied. Only 25% of the total area sprayed received an amount of water which is within ±10% of the actual mean amount applied. It is, therefore, important that the water content measurements be done at specific, representative locations.

The underdrain flow rate vs time could be approximated with straight lines on a log-log plot, making the computation of cumulative drainage very convenient. The rate increased approximately as the cube of time until the peak flow rate was reached and then decreased approximately as the reciprocal of time squared. For the continuous 5-hr applications, the peak flow occurred approximately 1 hr after the end of application.

Higher initial soil water content or saturation resulted in higher flow rates and, therefore,



PERMEABILITY,* SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS						
VERY SLOW	SLOW	MODERATELY SLOW	MODERATE	MODERATELY RAPID	RAPID	VERY RAPID
< 0.06	0.06–0.20	0.20–0.60	0.60–2.0	2.0–6.0	6.0–20.0	> 20.0

* MEASURED WITH CLEAR WATER

1 in./wk = 2.54 cm/wk

Figure 47. Design criteria for wastewater application rate vs soil permeability (EPA/COE 1977).

higher cumulative drainage. Consequently, it is possible to predict the approximate cumulative amount of drainage at any time during or after the application from the initial soil tension or saturation measurements. Also, once the peak flow rate has been determined, shortly after the end of application, it is possible to predict the approximate cumulative drainage 1 or 2 days after the application.

The water budget in the test area at the end of a typical 5-hr continuous application was calculated using the mean data from several applications done during the most typical soil water content conditions. The amount of water remaining in the soil was 77.3%, drainage was 3.5%, and 7.2% was lost due to evapotranspiration, leaving unaccounted 12% of the amount applied. Initially, the mean saturation (0- to 80-cm depth) was 74% (81.5% for the top 40 cm); at the end of application the 0- to 80-cm saturation was 80% (84% for the top 40 cm).

LITERATURE CITED

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Lambert, D.J. and H.L. McKim (1977) Deer Creek Lake on-land wastewater treatment system. *Proceedings of the 9th Annual Meeting on Waste Management, Cornell University.*

U.S. Environmental Protection Agency, U.S. Army Corps of Engineers and U.S Department of Agriculture (1977) Process *design manual for land treatment of municipal wastewater.* EPA 625/1-77-008 (U.S. Army Corps of Engineers EM 1110-1-501), p. 3-7.

APPENDIX A: DATA COMPILATIONS

Table A1. Climatological data.

Note: Data shown below were obtained each day at approximately 0900 hr. Therefore, the data obtained on a particular date actually represent the climatological conditions for the 24-hr period prior to observation.

Appl. No.	Date	Air Temp. (°C) Max.	Air Temp. (°C) Min.	Water Temp. (°C) Max.	Water Temp. (°C) Min.	Wind (Km hr^{-1})	Precip. (cm)	Net Pan Evap. (cm)
	9 Jun	-	-	28	18	-	-	-
1	10 Jun	-	21	33	22	3.3	0.05	0.51
	11 Jun	-	10	34	11	7.8	0.05	0.64
	12 Jun	25.5	8.5	28	10.5	3.1	Trace	0.87
	13 Jun	24.5	10	31	11.5	2.7	0	0.73
	14 Jun	22.5	12	26	12	1.9	0	0.41
	15 Jun	28	15.5	34	15	2.0	0	0.63
	16 Jun	29	15	32	15.5	2.3	0	0.56
	17 Jun	28.5	17	32	19	1.1	0	0.58
	18 Jun	30	16	37	17.5	3.4	0	0.38
	19 Jun	25	14.5	32	16	2.5	0	0.72
	20 Jun	26	15	32	18	2.2	0	0.66
	21 Jun	31	18	34.5	17	4.0	0.97	1.00
	22 Jun	30	18	34.5	17	3.4	0.03	0.37
	23 Jun	29	16	30.5	17	3.9	0.03	0.73
2	24 Jun	26	10.5	30	12	2.7	0	0.55
	25 Jun	20.5	5.5	27	9	2.1	0.28	0.45
	26 Jun	22	9.5	31	9	1.7	0.03	0.55
	27 Jun	25.5	11.5	33	12	1.8	0	0.64
	28 Jun	28	16	31	16	2.1	0	0.70
	29 Jun	29.5	19.5	32	17	4.3	0	0.70
	30 Jun	23	11	24	17	4.4	2.18	0.34
	Mean	26.5	13.8	31.2	15	3.0	0.17	0.60
3	1 Jul	19	14	20	13	4.1	1.12	0.07
	2 Jul	23	13	22	13	4.0	1.35	1.53
	3 Jul	-	-	-	-	-	-	-
	4 Jul	28	16	34	15	2.8	0.55	-
	5 Jul	21.5	10	24	11	2.5	0.08	0.38
	6 Jul	21.5	7	29	10	1.6	0	0.52
	7 Jul	23	9.5	31.5	10	1.8	0	0.05
4	8 Jul	25.5	11.5	31	13	2.8	Trace	0.85
	9 Jul	27	14.5	34	13.5	2.6	0.51	0.62
	10 Jul	21.5	19	36.5	17	1.7	0.05	0.18
	11 Jul	27	16	32	18	1.4	0.94	0.35
	12 Jul	28	19	33	19	3.1	0	0.51
	13 Jul	27	20.5	31	20	1.1	1.02	-
	14 Jul	23	18	36	14	3.8	0.05	-
5	15 Jul	29.5	19.5	34	20	2.7	0.10	-
	16 Jul	26.5	19.5	35	20	4.1	0	0.59
	17 Jul	30	16	34	18	3.0	0	0.76
	18 Jul	28	13.5	34	15	2.5	0	0.62
	19 Jul	28	9	33	12	1.5	0	0.70
	20 Jul	28	8.5	33	12	1.5	0	0.59
	21 Jul	29	16	35	15.5	1.3	0	0.54
6	22 Jul	29	18	34	19	1.6	0	0.50
	23 Jul	29.5	19	35.5	18.5	1.8	0	0.50
	24 Jul	31	19.5	34	19	3.9	0.05	0.61
	25 Jul	28	20	29	18	2.8	2.18	Overflow
	26 Jul	26	19.5	28	18	6.1	0.38	Overflow
	27 Jul	20.5	20	32	22	1.8	0.18	0.35
	28 Jul	29.5	20	32	18	5.2	0.13	0.61
	29 Jul	22	18.5	22	20	2.7	3.68	Overflow
	30 Jul	28	19.5	32	20	2.4	0.05	0.58
	31 Jul	29.5	22	34	20	3.2	Trace	0.59
	Mean	26.5	16.2	31.5	16.6	2.2	0.41	0.54

Table A1 (cont'd). Climatological data.

Appl. No.	Date	Air Temp. (°C) Max.	Air Temp. (°C) Min.	Water Temp. (°C) Max.	Water Temp. (°C) Min.	Wind (Km hr⁻¹)	Precip. (cm)	Net Pan Evap. (cm)
	1 Aug	31.5	19.5	34	18	-	-	-
	2 Aug	30.5	19.5	34	20	4.5	2.06	0.80
	3 Aug	25.5	15.5	30	18	3.4	0.03	0.35
	4 Aug	28	15.5	32	17	2.2	0	0.59
	5 Aug	30	18	38.5	18	2.9	0	0.49
	6 Aug	30.5	19	34	19	2.9	1.40	0.58
7	7 Aug	30	18.5	35	20	1.4	0	0.50
	8 Aug	31.5	18.5	34	20	4.8	0	0.68
	9 Aug	33	20.5	35.5	21	3.1	0	0.58
	10 Aug	32	22	31	21	3.4	0	0.54
	11 Aug	31	18	33	19	6.6	4.01	0.77
	12 Aug	20	11.5	21	12	2.4	0.58	0.16
	13 Aug	23	10	30	12	1.3	0.03	0.52
8	14 Aug	25	11	28	13	5.1	0	0.55
	15 Aug	23.5	7	24	9	6.4	0	0.28
	16 Aug	18	8	25	9	4.0	0	0.61
	17 Aug	21	8	29	11	1.6	0	0.48
	18 Aug	23.5	10	28	12	2.6	0.18	0.39
	19 Aug	26.5	18.5	27	15	5.0	1.91	0.56
9	20 Aug	29	18.5	34	18	2.4	0.05	0.57
	21 Aug	26	18.5	28	18.5	2.2	4.93	Overflow
	22 Aug	25	18	28	18	0.6	0.03	0.27
	23 Aug	26.5	18.5	29	19	1.8	0.10	0.36
	24 Aug	27	20	28	21	2.4	1.32	0.20
	25 Aug	25	15	27	17	1.8	0.23	0.63
	26 Aug	24.5	16	30	17	0.7	1.47	Overflow
	27 Aug	22	16.5	22	18	0.8	0	0.39
	28 Aug	26.5	19	25	19	2.9	0	0.28
10	29 Aug	28.5	18.5	31	19	2.2	0	0.27
	30 Aug	26.5	18	28	18	4.5	0	0.36
	31 Aug	29	15.5	32	18	1.3	0	0.48
	1 Sept	29.5	18.5	34	19	1.4	0	0.48
	Mean	26.8	16.2	30	17	2.9	0.59	0.47

Table A2. Soil tension data.

Appl. No.	Date	Time (hr)	Precip. (cm)	Soil Tension (cm of water), Location (field, depth): Grass 15 cm	Grass 30 cm	Grass 56 cm	Grass 76 cm	Corn 30 cm	Corn 71 cm	Corn 76 cm	Alfalfa 56 cm
2	24 Jun	0	0	110	700	940	160	370	150	60	560
		6.5		20	420	60	100	70	50	60	370
	25 Jun	22	0.28	60	60	100	150	130	90	60	150
		30		60	60	90	160	120	70	60	250
	26 Jun	46	0.03	80	80	110	170	140	100	60	250
		54		130	100	100	180	130	90	80	290
	28 Jun	98	0	500	200	120	180	140	140	60	250
	29 Jun	122	0	180	210	120	180	140	110	60	180
3	1 Jul	0	1.12	50	40	90	140	110	70	60	170
		3		20	20	60	110	70	50	60	190
		6		20	20	60	90	50	50	60	190
		7.5		20	20	60	80	50	50	60	190
	2 Jul	24	1.35	30	20	60	120	70	50	60	190
		31		60	50	80	140	90	70	60	210
	3 Jul	46.5	0	70	60	90	130	110	80	60	210
	4 Jul	71	0.55	30	20	100	140	100	70	60	210
		77.5		40	30	80	140	120	80	60	210
	5 Jul	100	0.08	80	70	90	160	130	100	60	230
	6 Jul	121	0	120	100	110	160	140	120	60	230
		127		160	100	120	160	130	120	80	230

Table A2 (cont'd). Soil tension data.

Appl. No.	Date	Time (hr)	Precip. (cm)	Soil Tension (cm of water) Location (field, depth)							
				Grass				Corn			Alfalfa
				13 cm	30 cm	56 cm	76 cm	30 cm	71 cm	76 cm	56 cm
	7 Jul	154	0	310	110	180	150	130	120	80	230
4	8 Jul	0	0	320	140	90	150	150	110	70	230
		2.5		30	130	100	170	130	70	80	230
		6		20	40	60	140	90	50	60	200
		8		30	30	60	120	90	50	60	200
	9 Jul	25	0.51	30	20	60	110	90	50	60	210
		30		30	30	60	120	140	50	60	210
	10 Jul	49	0.05	60	60	80	140	130	70	80	210
		58		20	30	60	140	90	50	60	210
	11 Jul	72	0.94	50	50	80	150	130	80	80	210
		82		70	60	70	140	120	70	80	210
	12 Jul	98	0	90	80	80	140	130	80	80	220
	13 Jul	124	1.02	40	40	70	140	120	60	80	210
5	15 Jul	0	0.10	90	70	80	140	130	70	80	210
		3		30	40	70	160	140	90	60	210
		6		20	20	60	120	80	50	60	200
	16 Jul	22	0	40	40	60	130	110	50	60	200
		30		80	60	60	140	100	70	70	220
	17 Jul	46	0	90	60	70	140	130	70	60	230
		53		120	80	60	140	110	70	80	230
	18 Jul	79	0	220	100	80	160	130	90	100	230
	19 Jul	103	0	460	140	80	190	130	110	120	230
6	22 Jul	0	0	660	340	100	160	150	210	80	190
		2.5		40	380	100	180	150	170	100	210
		5.5		20	200	100	180	110	60	60	210
	23 Jul	23	0	50	70	100	160	150	70	70	190
	25 Jul		2.18	30	30	60	110	50	50	110	-
	26 Jul		0.38	60	60	60	150	130	50	80	-
	27 Jul		0.18	80	80	70	150	130	110	80	-
	28 Jul		0.13	20	20	60	130	100	50	60	-
	29 Jul		3.68	20	20	60	90	60	50	60	-
				40	40	60	130	90	70	60	-
	30 Jul		0.05	55	45	60	120	50	40	110	-
				70	70	70	160	70	60	120	-
	31 Jul		0	70	70	80	140	120	60	70	-
				110	90	80	170	140	110	100	-
	1 Aug		0	120	80	80	150	130	60	80	-
	2 Aug		2.06	20	40	60	110	40	100	60	-
	3 Aug		0.03	90	60	80	130	40	130	60	-
7	7 Aug	0	0	40	70	120	140	130	60	70	230
		3		30	50	70	150	130	50	70	210
		7		20	20	60	120	90	50	60	210
	8 Aug	23.5	0	20	40	80	130	100	50	60	210
	9 Aug	46	0	20	60	100	120	120	50	70	210
	10 Aug	77	0	40	100	120	140	120	70	70	230
	11 Aug	104	4.01	20	20	60	80	100	50	60	210
	12 Aug	128	0.58	20	60	100	140	110	50	60	210
	13 Aug	144	0.03	40	60	110	140	130	60	60	210
8	14 Aug	0	0	40	70	150	120	130	70	60	230
		2.5		40	80	70	150	110	50	60	210
		8		20	20	60	80	70	50	60	190
	15 Aug	24	0	20	40	80	120	110	50	60	190
	16 Aug	48	0	10	70	120	120	130	50	60	190
	17 Aug	72	0	60	80	140	130	140	50	60	190
	18 Aug	94	0.18	80	100	160	160	140	60	80	190
		103		40	60	80	140	140	50	90	190
	19 Aug	121	1.91	30	60	100	140	110	90	80	190
9	20 Aug	0	0.05	40	60	110	120	120	70	60	190
		2.5		20	30	70	130	100	50	60	190
		5		20	20	60	90	70	50	60	190
	21 Aug	22	4.93	20	20	60	70	70	50	60	190
		34		20	40	80	120	70	50	60	190

Table A2 (cont'd). Soil tension data.

Appl. No.	Date	Time (hr)	Precip. (cm)	Soil Tension (cm of water) Location (field, depth) Grass 13 cm	Grass 30 cm	Grass 56 cm	Grass 76 cm	Corn 30 cm	Corn 71 cm	Corn 76 cm	Alfalfa 56 cm
	22 Aug	56	0.03	30	70	110	140	90	50	70	190
	23 Aug	81	0.10	30	60	110	140	90	50	60	190
	24 Aug	105	1.32	20	30	70	120	60	50	60	190
	27 Aug	175	0	20	50	90	130	100	60	70	190
	28 Aug	193	0	30	70	120	140	110	60	70	190
		200		20	70	120	140	130	70	70	190
10	29 Aug	0	0	40	80	120	140	130	70	70	190
		3		20	40	60	140	120	70	60	190
		7.5		20	20	60	120	100	50	60	190
	30 Aug	21	0	20	30	70	100	90	50	60	190
		30		20	50	100	120	100	60	60	190
	31 Aug	46	0	20	50	110	130	110	60	60	190
		55		40	80	130	160	130	70	80	190
	1 Sept	69	0	40	80	140	160	130	70	80	190
		78		40	100	160	160	130	90	100	190

Table A3. Soil water content data.

Appl. No.	Date	Time (hr)	Precip. (cm)	Volumetric Water Content, V_W (%) Depth (cm) 5	12.5	25.5	45.5	55.5	63.5	76.5	91.5
				Alfalfa							
2	24 Jun	0	0	-	23.1	34.3	37.2	28.4	28.2	37.3	36.5
		2.5		-	22.4	34.5	24.1	24.4	29.9	28.9	26.2
		6		-	35.7	31.0	38.8	37.0	34.0	36.1	-
	25 Jun	24	0.28	-	29.2	31.0	27.5	28.5	23.1	25.4	27.2
	26 Jun	48	0.03	-	30.6	23.7	41.3	40.9	44.7	41.4	42.2
	27 Jun	72	0	-	29.7	34.6	22.6	18.8	20.2	21.4	22.6
	29 Jun	120	0	-	27.1	33.7	37.0	35.9	35.8	39.4	42.2
	30 Jun	144	2.18	-	38.4	29.1	29.4	33.0	39.8	46.4	40.0
5	15 Jul	0	0.10	31.2	28.6	43.0	27.2	-	22.7	20.4	22.2
		2.5		33.3	29.7	39.8	25.8	21.3	22.9	21.4	27.1
		5		28.8	31.4	36.5	21.7	22.7	21.0	21.8	21.6
	16 Jul	24	0	31.6	26.2	36.6	30.0	39.4	35.7	29.1	-
	18 Jul	72	0	29.2	27.7	40.0	24.2	31.2	33.1	42.3	36.2
6	22 Jul	0	0	20.9	20.0	38.6	27.1	25.9	22.2	22.0	21.6
		2.5		30.8	24.3	31.9	36.8	30.9	28.2	35.5	25.2
		5		34.8	27.9	37.4	27.7	21.6	20.9	23.9	23.1
	24 Jul	48	0.05	33.9	37.2	34.7	27.1	28.6	17.1	19.9	29.8
	25 Jul	72	2.18	39.4	30.8	41.3	38.3	37.5	35.5	36.1	-
	26 Jul		0.38	45.6	44.5	48.1	47.5	46.3	45.5	48.9	-
	27 Jul		0.18	30.0	29.8	37.4	37.0	35.0	42.6	43.0	38.0
	29 Jul		3.68	32.3	29.0	45.7	41.8	38.0	46.9	43.8	44.7
	30 Jul		0.05	34.8	31.6	42.9	41.7	40.2	43.9	47.7	41.3
	1 Aug		2.06	33.0	27.9	28.2	37.3	-	31.7	24.6	23.1
	2 Aug		0.03	34.2	30.0	38.9	36.2	27.4	21.8	22.4	21.6
8	14 Aug	0	0	31.5	34.5	42.6	37.6	35.8	41.7	40.3	44.1
		5		45.6	40.9	47.8	43.0	50.2	36.2	-	-
				Corn							
3	1 Jul	0	1.12	-	40.6	33.4	26.8	22.2	19.0	25.1	26.0
		2.5		-	32.1	35.3	38.4	41.4	35.8	32.9	25.7
		5		-	24.9	37.0	35.1	31.6	30.3	-	-
	3 Jul	46	0	-	35.8	39.1	27.2	29.8	29.7	35.2	29.2
	4 Jul	77	0.55	-	30.4	31.0	35.5	35.7	29.5	-	-
	5 Jul	96	0.08	-	32.6	33.3	24.0	18.5	18.4	17.0	-

Table A3 (cont'd). Soil water content data.

Appl. No.	Date	Time (hr)	Precip. (cm)	Volumetric Water Content, V_w (%) Depth (cm)							
				5	12.5	25.5	45.5	55.5	65.5	76.5	91.5
	8 Jul	0	Trace	-	31.7	45.4	38.8	40.0	40.4	31.8	-
		2.5		-	29.6	30.4	40.5	47.9	45.3	32.0	31.4
		8		-	30.6	40.4	23.8	27.8	23.6	22.3	26.6
	10 Jul	59	0.05	-	29.2	28.3	33.3	27.0	-	-	-
	11 Jul	82	0.94	-	32.2	48.1	40.1	41.2	43.2	38.5	31.0
	15 Jul	0	0.10	31.3	30.3	32.4	28.1	29.8	22.0	18.6	22.9
		2.5			30.9	34.6	34.6	18.1	25.7	21.7	27.4
		5		33.4	32.4	41.8	28.1	24.2	22.2	-	-
	27 Jul		0.18	33.1	33.2	32.3	46.3	35.7	30.2	27.8	28.7
	29 Jul		3.68	43.2	39.6	36.0	31.6	25.9	26.0	29.5	27.1
	30 Jul		0.05	36.4	33.9	42.2	34.5	27.6	25.2	19.0	24.3
	1 Aug		2.06	24.4	32.9	38.4	29.5	29.2	35.9	18.5	41.2
	2 Aug		0.03	34.0	35.2	40.8	34.3	27.1	21.7	20.4	25.0
								Grass			
	8 Jul	0	Trace	-	28.5	37.7	29.1	31.1	27.7	20.3	23.7
		2.5		-	32.2	43.7	42.6	45.0	38.8	34.4	41.1
		8		-	30.4	37.2	26.1	27.5	30.2	-	-
	9 Jul	29	0.51	-	25.8	26.6	27.2	32.9	30.0	18.1	23.1
	10 Jul	57	0.05	-	29.7	31.3	31.0	28.4	27.7	21.3	24.8
	11 Jul	82	0.94	-	31.4	35.5	26.3	23.5	19.1	17.7	21.0
	15 Jul	0	0.10	31.2	30.7	42.6	29.4	24.1	-	-	-
		2.5		37.0	30.4	42.0	25.8	29.4	28.7	-	-
		5		34.3	31.5	36.4	33.5	29.8	29.8	22.1	-
	16 Jul	24	0	21.5	38.6	30.6	38.5	28.8	22.2	25.7	-
	18 Jul	72	0	16.8	18.3	23.3	21.3	22.7	21.2	13.5	-
	22 Jul	0	0	21.3	31.3	27.0	36.2	29.7	32.1	24.6	38.6
		2.5		37.9	37.6	27.2	37.4	33.6	33.2	-	-
		5		28.3	33.0	30.1	36.2	36.4	37.7	29.3	25.8
	25 Jul	72	2.18	27.9	41.0	33.4	39.1	41.8	41.6	28.2	30.2
	26 Jul		0.38	26.5	31.1	33.4	39.4	40.5	40.3	33.4	42.4
	27 Jul		0.18	30.3	42.3	33.5	34.5	35.3	39.9	46.4	44.3
	29 Jul		3.68	37.6	41.1	32.1	38.2	38.5	36.0	26.5	31.1
	30 Jul		0.05	30.0	31.8	33.5	39.6	31.6	23.2	20.4	22.5
	1 Aug		0	27.1	26.7	29.2	26.6	26.4	25.3	29.6	39.8
	2 Aug		2.06	30.6	30.1	39.4	35.6	41.0	36.1	36.2	39.5
	7 Aug	0	0	21.9	19.5	30.8	27.2	37.8	36.8	27.4	37.7
		2.5		20.7	20.2	37.9	34.2	33.2	29.8	27.7	36.7
		5		24.9	26.4	45.9	30.8	30.2	31.4	27.8	38.8
	14 Aug	0	0	27.4	34.0	34.1	26.8	35.4	28.5	28.7	-
		2.5		31.7	37.7	34.2	43.4	36.0	33.6	42.4	-
		6		29.7	33.2	31.8	34.7	31.3	42.6	27.1	34.6

Table A4. Drainage flow data (point 5).

Applic. No.	Date	Time (hr)	Rate* (L min^{-1})	Precip. (cm)
2	24 Jun	0	0.8	0
	"	1	1.0	
	"	2	1.7	
	"	3.2	2.3	
	"	4	5.7	
	"	4.5	10.2	
	"	5	22.3	
	"	6.5	26.1	
	"	7.5	21.2	
	"	8.2	17.4	
	"	9.2	12.5	
	25 Jun	17.5	6.8	0.28
	26 Jun	43.5	2.3	0.03
	27 Jun	67.5	0.8	0
	28 Jun	91.5	0.8	0
3	1 Jul	0	11.4	1.12
	"	0.75	12.5	
	"	1.75	53	
	"	3	153	
	"	4	167	
	"	5	370	
	"	7.5	337	
	"	8.5	271	
	"	9.2	243	
	"	10.2	216	
	2 Jul	22	58.7	1.35
	"	29	40.1	
	3 Jul	53	10.2	0
	4 Jul	71	19.3	0.55
	"	77	11.7	
	5 Jul	100	4.5	0.08
	6 Jul	121	4.5	0
4	8 Jul	0	0.7	0
	"	1.2	1.4	
	"	2.5	11	
	"	4	70	
	"	4.7	92	
	"	5.7	197	
	"	6	226	
	"	9	92	
	"	10	79	
	"	11	69	
	9 Jul	22.5	60	0.51
	"	29.5	41.3	
	10 Jul	49	17.4	0.05
	"	58	33.3	
	11 Jul	72	18.6	0.94
	12 Jul	103	5.3	0
5	15 Jul	0	4.9	0.10
	"	1.5	17	
	"	2	46.6	
	"	3.5	119.6	
	"	5	338	
	"	5.7	454	
	"	6	628	
	"	7	420	
	"	8.5	280	
	16 Jul	22	78.4	0
	"	31	37.5	
	17 Jul	44.5	19.7	0
	"	53	12.9	
	19 Jul	92	2.8	0
	20 Jul	120	1.0	0
6	22 Jul	0	0.3	0
	"	2	2.2	
	"	3	4.4	
	"	4.7	19.7	
	"	5.5	35.7	
	"	6.5	33.1	
	"	8	21.2	
	"	8.5	20.1	
	"	9	17.4	
	"	11	13.6	

Table A4 (cont'd). Drainage flow data (point 5).

Applic. No.	Date	Time (hr)	Rate* ($L\ min^{-1}$)	Precip. (cm)
	23 Jul	23.5	3.5	0
	25 Jul	70	85.2	2.18
	26 Jul	94	36	0.38
	27 Jul	118	15.1	0.18
	28 Jul	141	14	0.13
	29 Jul		296	3.68
	30 Jul		53	0.05
	31 Jul		19.7	0
	1 Aug		11.7	0
	2 Aug		59.4	2.06
	3 Aug		36	0.03
	4 Aug		15.5	0
7	7 Aug	0	11.4	0
	"	1.5	22	
	"	2.5	109	
	"	3.5	165	
	"	4.5	297	
	"	6	821	
	"	9	273	
	"	10	240	
	"	11	204	
	8 Aug	21	87.8	0
	"	22.5	82.5	
	9 Aug	46.5	28.8	0
	11 Aug	103	366	4.01
	12 Aug		171	0.58
	13 Aug		81	0.03
8	14 Aug	0	29.5	0
	"	3	87.1	
	"	5	409	
	"	5.5	539	
	"	6	645	
	"	7.5	519	
	"	9	376	
	"	11	262	
	"	13	205	
	"	14	202	
	15 Aug	15	173	0
	"	21	118	
	"	22	107.5	
9	20 Aug	0	71.5	0.05
	"	1	76.1	
	"	2	85.2	
	"	3	274	
	"	6	1325	
	"	8	716	
	"	9	484	
	"	10	368	
	"	11	321	
	21 Aug	22	568	4.93
10	29 Aug	0	48.5	0
	"	2	58.3	
	"	3	78.4	
	"	4	129	
	"	5	143	
	"	6	329	
	"	7	488	
	"	8	491	
	"	9	627	
	"	10	519	
	"	11	412	
	"	12	366	
	30 Aug	13	302	0
	"	19	185	

* In the analysis, normalized rate values were used (the initial rate at $t = 0$ hrs was subtracted from the actual rate), converted to units of $L\ hr^{-1}$.

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